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欧文海洋報告は、1949年から刊行されてきましたが、今号をもって廃刊とします。長年のご愛読に感謝致します。

Preface to the final issue

We have decided to discontinue the publication of the Oceanographical Magazine. We would like to appreciate all the readers for having referred to this magazine.

The Oceanographical Magazine

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A Preliminary Study of the Temperature Structure in the North Central Japan Sea

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Abstract: Japan-Korea-Russia Joint Expedition, to clarify radioactive contamination of the Japan Sea due to the dumping of radioactive wastes by Russia (and the former USSR), was conducted from March to early April 1994 in the north central part of the Japan Sea. During the expedition, we carried out the XBT and CTD measurements to understand the hydrographic feature of surveyed area. Water mass in early spring in the north central part of the Japan Sea (north of 40°N) was characterized as cold (less than 2.5°C) and of salinity homogeneous water (34.07±0.02). Vertical profiles of seawater temperature suggest that water mass can, at least, be divided into two parts: one is the surface water and another the Japan Sea Proper Water (JSPW). The spatial distributions of seawater temperature suggest that an anticyclonic eddy coupled with a cyclonic eddy was present in the north central part of the Japan Sea. The hydrographic information will be important to understand the distribution of radionuclides in the north central part of the Japan Sea.

1. Introduction

The Japan Sea (the East Sea) is a basin almost enclosed by land masses with an area of 1,008,000km^2 and a mean depth of about 1,350m. Most of the deep waters in the Japan Sea is characterized as the Japan Sea Proper Water (JSPW), which is extremely homogeneous in salinity (34.04–34.10), temperature (0.2–0.5°C), and higher oxity (220–250 μmol kg^{-1}) (Asaoka, 1987). The upper layer of the Japan Sea can be divided into two regions at the Polar Front near 40°N latitude as a border; the cold water region exists to the north of the front and the warm water region to the south of the front. The cold water region is characterized by the surface water with lower temperature and lower salinity, whereas the warm water region shows higher temperature and higher salinity in the surface water due to the Tsushima Warm Current.

The current studies about the physical aspects of the Japan Sea, which were reviewed by SHUTO (1982), aimed at the following objectives:

1. Production processes of JSPW (SUDA, 1932; OOWADA and TANIOKA, 1971; NITANI, 1971, 1972; NISHIYAMA *et al*, 1990, 1993; SENJYU and SUDO, 1994);
2. Dynamic features of Tsushima Warm Current water (YOON, 1981a, b; KAWABE, 1982; SEKINE, 1986);
3. General circulation of water mass in the Japan Sea (SEKINE, 1989, 1992);

4. Mixing processes between JSPW and Tsushima Warm Current water;
5. The properties of cold and warm eddies.

In order to understand the oceanographic features of the Japan Sea, some intensive theoretical and observational studies have been carried out. However, observational data available in analyzing the physical and chemical features of the Japan Sea are limited in the south part of the Japan Sea. Although the north part of the Japan Sea is a significant area because of the formation of upper JSPW in winter due to deep convection (SENJYU and SUDO, 1994), there are very few observational data, especially, in the winter season. According to the recent study to use historical data, SEUNG and YOON (1995) revealed that winter convection reached down to about 1,000m depth near Vladivostok.

In March 1994, the Japan-Korea-Russia Joint Expedition was carried out in the north central part of the Japan Sea, the main purpose of which was to determine the radioactive contamination of seawater, biota and sediment resulting from the radioactive waste dumping by Russia (and the former USSR). In this expedition, we carried out CTD and XBT casts as well as the collection of water, sediment and biota samples. We present here temperature data obtained from the XBT measurements and describe a snap shot of the oceanographic structure of the north central Japan Sea in the early spring season.

2. Observations

Measurements of seawater temperature in the surface layer were carried out by using an XBT system (Tsurumi Seike) in the cruise of the RV "OKEAN", belonging to Far Eastern Hydrometeorology Research Institute (FEHRI, Vladivostok), during March and April 1994 for the Japan-Korea-Russia Joint Expedition. CTD measurements were carried out by a Russia group at water sampling sites (N1 to N7) (SETO *et al.*, 1994). Seawater temperature data for the XBT measurements were recorded with 1m depth interval from surface to 760m depth. Sampling sites together with the cruise track are shown in Fig. 1. All of observation sites were located north of 40°N latitude, which corresponds to the cold water region. Spatial sampling intervals were ranged from 20 miles to 40 miles.

3. Results

According to the XBT and CTD measurements (SETO *et al.*, 1994) the sea surface temperature (SST) in the north central part of the Japan Sea (north of 40°N) was less than 2.5°C from March to early April, 1994, which is characterized by cold water with a homogeneous salinity of 34.07. The temperature profiles to 760m depth was comprised of two or three layers with weak thermoclines. The smallest temperature difference between surface mixed layer and deep water (about 0.4°C) was observed at the St. N6.

In order to understand the structure of water mass in the north central part of the Japan Sea, vertical temperature cross sections and horizontal temperature distributions at 10m, 200m and 500m depth were examined (Fig. 2a, 2b and 2c, and Fig. 3a, 3b and 3c). The lowest SST (0.89°C) was observed at the St. N6 (Fig. 2a and 3a), whereas the highest SST (3.91°C) was found in the St. X5 (Fig. 2c and 3a). A general trend is that the SST decreases in the

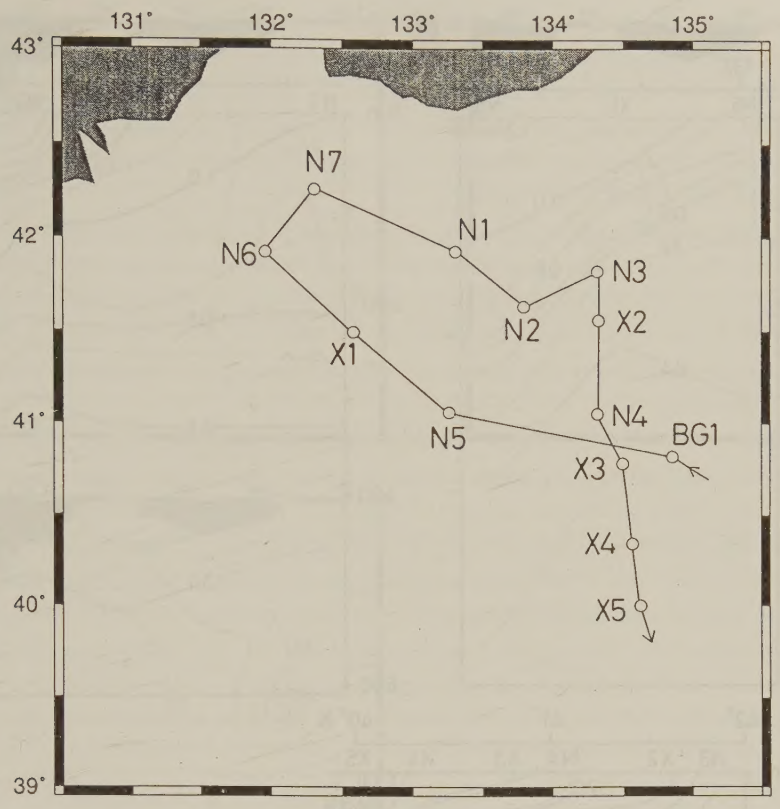

Fig. 1 Cruise tract and sampling points in the central Japan Sea.

northwest of the Japan Sea as shown in Fig. 3a and a thermal front was clearly recognized near 40°N (Fig. 2c), which corresponds to the Polar Front in the Japan Sea. The surface water layer of the JSPW in the north central Japan Sea was the thinnest at the St. N6 (120m) and thickest at the St. N4 (770m). The water mass at more than 500m depth except St. N4 was characterized by the typical JSPW with sea water temperature of less than 0.5°C.

Each of the three cross sections indicates that the north central Japan Sea was not occupied by a uniform water mass. Fig. 2a, 3a, and 3c show that a cold water mass, which may reflect the upwelling of deep waters, was present around the St. X1 as seen in the layer deeper than 200m, whereas a warm water mass was present near the St. N4 at the layer deeper than 200m as seen in Fig. 2c and 3c. The result suggests that anticyclonic and cyclonic eddies with meso-scale extent coexist in the north central Japan Sea. As another feature, it is worthy to be pointed out that the structure of the eddy seems to disappear in the surface layer, which is a different feature from that in the Pacific. It, however, must be noted that temperature difference between cold and warm eddies in the north central Japan Sea (less than 0.6°C at 200m depth) was much smaller than that in the Tsushima Current region and the North Pacific. The obtained

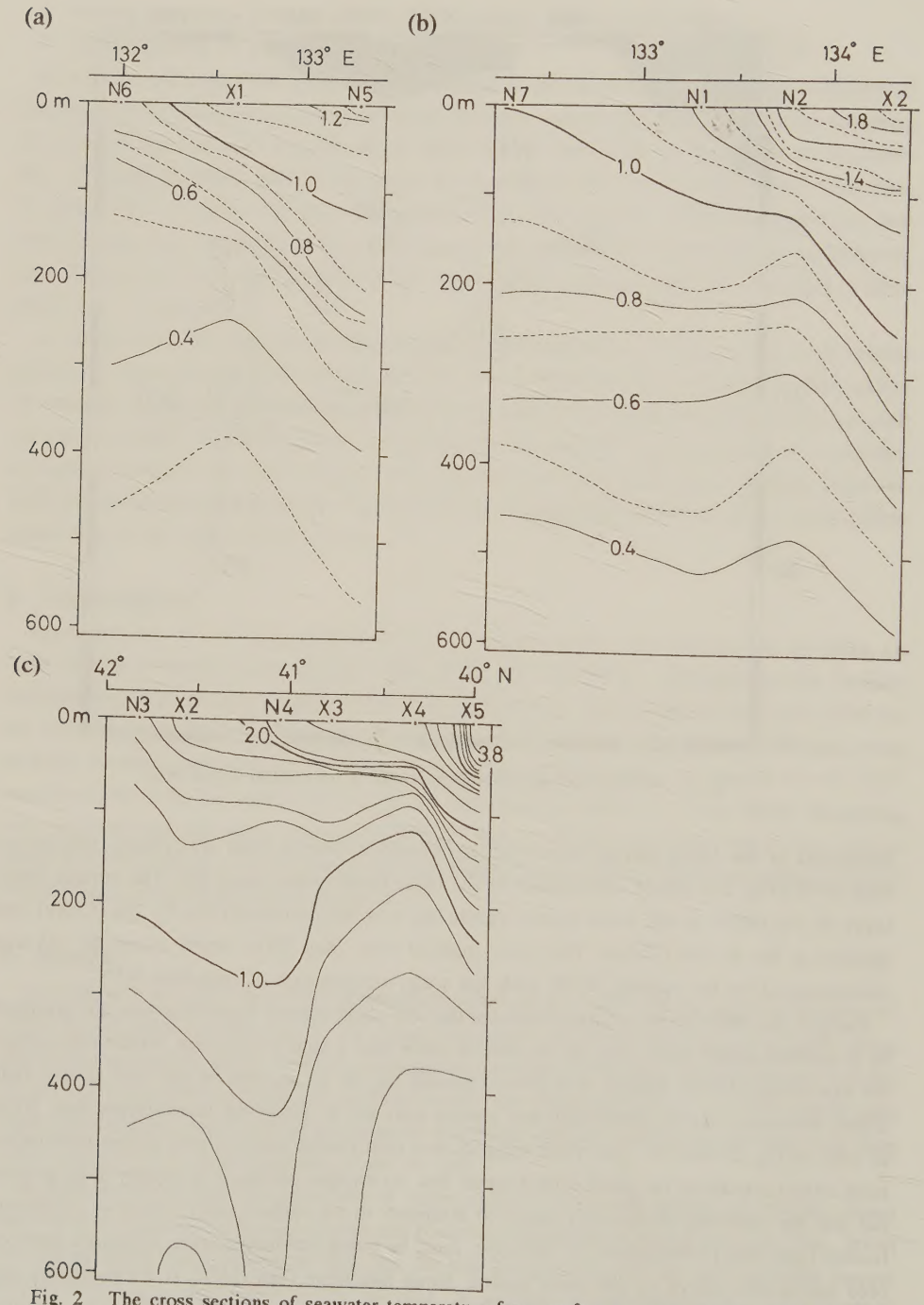

Fig. 2 The cross sections of seawater temperature from surface to 600m depth. a: N6-N5, b: N7-X2, c: N3-X5.

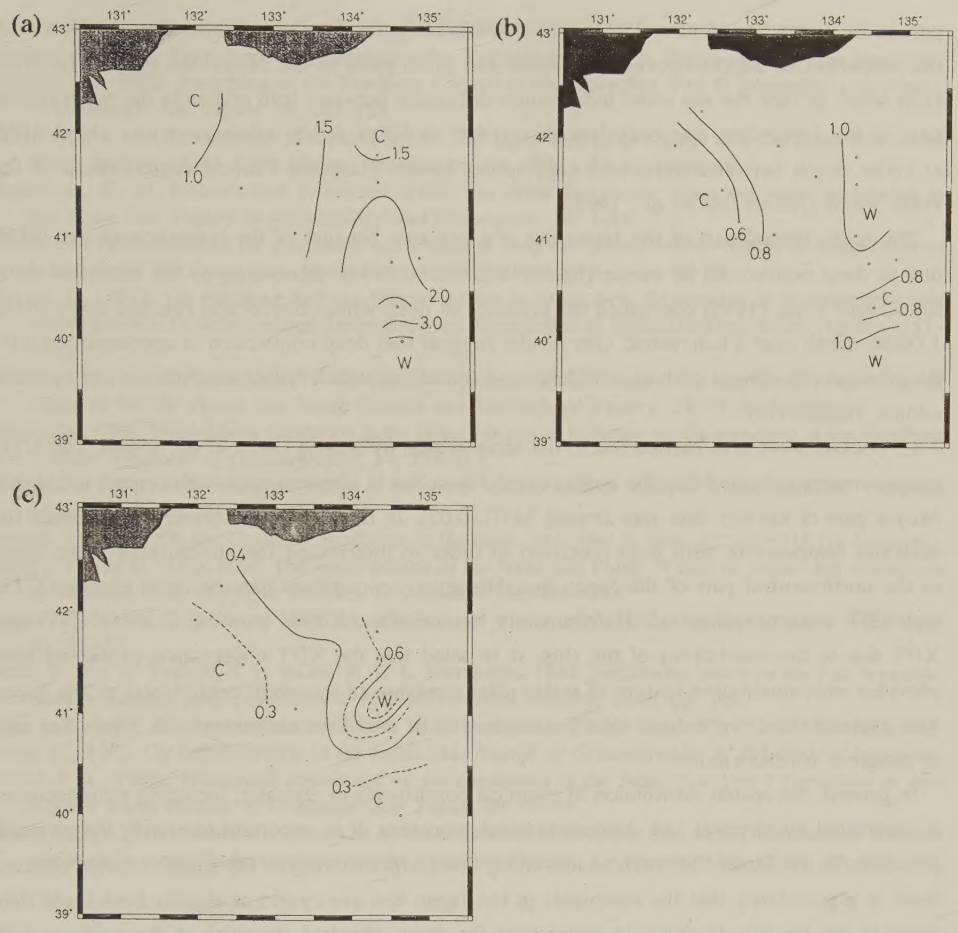

Fig. 3 The distribution of seawater temperature at 10m (a), 200m (b) and 500m (c) depth.

thermal structure suggests that a surface flow from south to north was present from 133°E to 134°E longitude, and from 40°N to 42°N latitude in this season.

4. Concluding Remark

According to the oceanic circulation model in the Japan Sea (SEKINE, 1992), the wind-driven circulation dominates due to seasonal intensification of the wind stress. In spring, the circulation is characterized by the oceanic response to the strong wind-driven circulation formed in the preceding winter. This suggests that an anticyclonic eddy, which is formed by the wind stress, is present in the north central Japan Sea in winter and spring seasons. The result of the present survey suggests that a cyclonic eddy coupled with an anticyclonic eddy with meso-scale occurred in the north central part of the Japan Sea; that is, the properties of the eddies seem to differ from those of the model (SEKINE, 1992). The coupling of eddies has been observed in the south

part in the Japan Sea (SHUTO, 1982), which is related to the Tsushima Warm Current. However, the properties of eddies between the south and north parts in the Japan Sea may differ from each other. In fact, the sea water temperature difference between both eddies in the north central part of the Japan Sea was only less than 0.6°C at 200m depth, whereas it was about 10°C at 100m depth between warm and cold eddies in the Tsushima Current region south of the Polar Front (NISHIYAMA *et al.*, 1993).

The north central part of the Japan Sea is a key area because of the formation of the JSPW due to deep convection in winter (SENJYU and SUDO, 1994). According to the historical data, SUENG and YOON (1995) confirmed the presence of deep winter convection reached down about 1,000m depth near Vladivostok. Our results suggest that deep convection is accompanied with the physical phenomena such as subsidence and upwelling, which reflect anticyclonic and cyclonic eddies, respectively.

CTD casts were also carried out in the same region by Russia (SETO *et al.*, 1994). The CTD measurements indicated that the north central Japan Sea is homogeneous with respect to salinity (major part of salinity data was around 34.07±0.02). It, therefore, is necessary to measure the seawater temperature with high precision in order to understand the structure of water mass in the north central part of the Japan Sea. However, temperature data between Russian CTD and XBT were not identical. Unfortunately, we cannot calibrate between Russian CTD and XBT due to the restrictions of the ship. It is noted that the XBT observation presented here provides only qualitative feature of water mass structure in the north central part of the Japan Sea. Nevertheless, we believe that the result will be useful to understand the Japan Sea and to progress further studies.

In general, the spatial distribution of chemical constituents in seawater, including radionuclides, is controlled by physical and biogeochemical processes. It is important to clarify the physical processes in the Japan Sea, such as upwelling and surface mixing in the winter season, because there is a possibility that the chemicals in the Japan Sea are cycled at shorter time-scale than those in the Pacific. In order to understand the detail physical structure of the north part of the Japan Sea, precision CTD measurements with a sampling interval of 15 miles will be required considering small changes of both temperature and salinity.

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日本海中北部の水温構造について

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概要

1994年3月から4月にかけて、日本海（東海）にロシア（および旧ソ連）により投棄された放射性廃棄物の影響を調査する目的で、日本海中北部で日韓露共同調査が行われた。この観測航海に際して、北部日本海の海況を把握するために、XBT観測を行った。初春期の、北部日本海の海洋観測データは極めて限られているばかりでなく、冬期の海洋の混合が終わった時期であるので、日本海の物質循環を解明するためには重要であると考える。観測結果によると、この時期、北緯40°以北の日本海の比較的広い海域は2.5°C以下の冷水で占められていることがわかった。全体では、低温の海水で、占められているものの、この海域には低気圧性と高気圧性の中規模渦が存在していることを水温のデータは示唆している。ただし、両者の温度傾度は小さい。これらの中規模渦は、放射能の分布に影響を与える可能性があるため重要である。

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Seasonal Variation and Long-term Trends of the Oceanographic Conditions along a Fixed Hydrographic Line Crossing the Kuroshio in the East China Sea.

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Abstract: Nagasaki Marine Observatory has seasonally carried out hydrographic observations on the section PN to cover the Kuroshio and the continental shelf in a central portion of the East China Sea since the spring of 1972. This study analyzes the seasonal variations and long-term trends of sea water temperature, salinity and geostrophic volume transport of the Kuroshio.

Beside the seasonal variation near the sea surface, water temperature and salinity in autumn in the intermediate layer of the Pacific side of the Kuroshio decrease as well as the geostrophic volume transport of the Kuroshio. The drop of water temperature and salinity in autumn is not due to the replacement of water mass but upward shift of the thermocline and halocline in the intermediate layer. In the intermediate layer of the Kuroshio and in some other layers, significant long-term trends are found in both water temperature and salinity. Water temperature increased 0.6°C and salinity decreased 0.05 psu during the past 20 years.

1. Introduction

Hydrographic observations have been carried out at every season of a year on the PN-line by the Nagasaki Marine Observatory (NMO) since 1972 to monitor the oceanographic conditions and the background marine pollution. Fig. 1 shows the location of observation stations along the PN line. FUJIWARA *et al.* (1987) reported that the maximum current velocity, corresponding to the Kuroshio axis along the PN line, is found in a region between PN-3' and PN-4 near the continental shelf break by analyzing the sea surface current velocity measured with GEK. They also showed that the southwestward Kuroshio counter current is analyzed in the area south of PN-2. KONDO (1985) demonstrated that continental shelf region (PN-5 – PN-9) is occupied with the continental coastal water by analyzing water temperature and salinity at 50m depth and above the bottom layer.

FUJIWARA *et al.* (1987) studied the seasonal variation of water temperature and salinity along the PN line using the seasonal means and their standard deviation of water temperature, salinity and dissolved oxygen. Their study was based on data obtained from 1972 to 1981 observed by the Nagasaki Marine Observatory. They indicated that the seasonal variation of them below 200m depth of the Kuroshio region is smaller than those in the surface layer. They also noted that the average of the geostrophic volume transport in autumn is relatively small compared

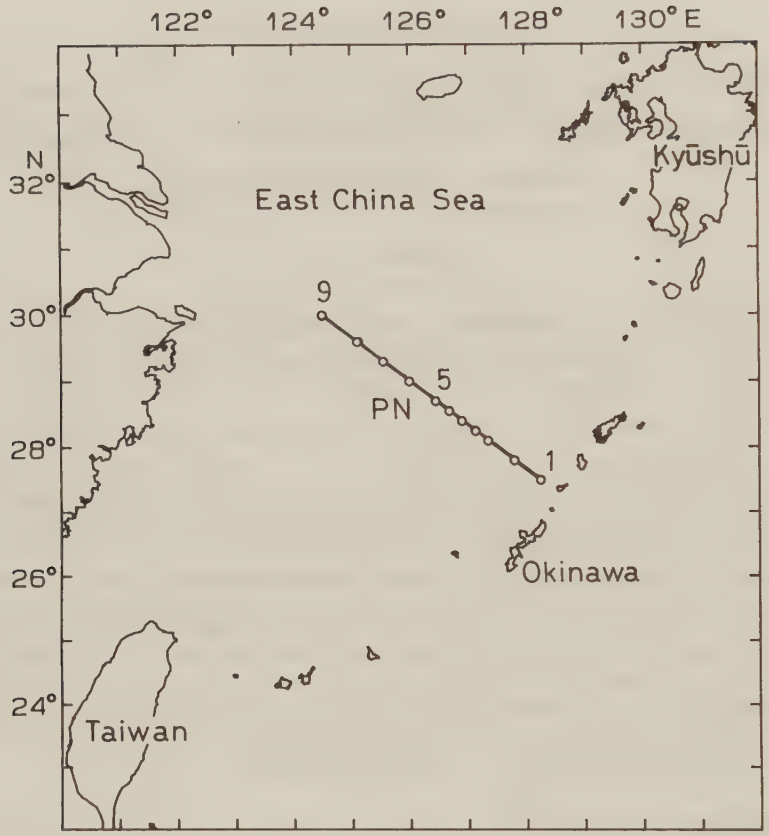

Fig. 1 Location of observation stations along the PN-line.

with other seasons.

In this study, the observation period is 12 years longer compared with the report of FUJIWARA *et al.* (1987). The present study deals with seasonal variation of sea water temperature and salinity below 200m depth that was not stated in the previous studies, along with their long-term trends.

2. Data

The present study uses the data obtained from 1972 to 1993. Observation stations from PN-1 to PN-9 are evenly distributed with intervals of 30 nautical miles with two additional stations, PN-3' and PN-4', over the continental shelf break near the Kuroshio axis. As shown in Fig. 2, observation data in winter, spring, summer and autumn were obtained in January or February, in April or May, in July or August and in September or October, respectively. The observation in autumn 1972 was carried out a month later than the mean observation period for autumn, and the data obtained in the autumn is not included in the analysis. Most of the observations

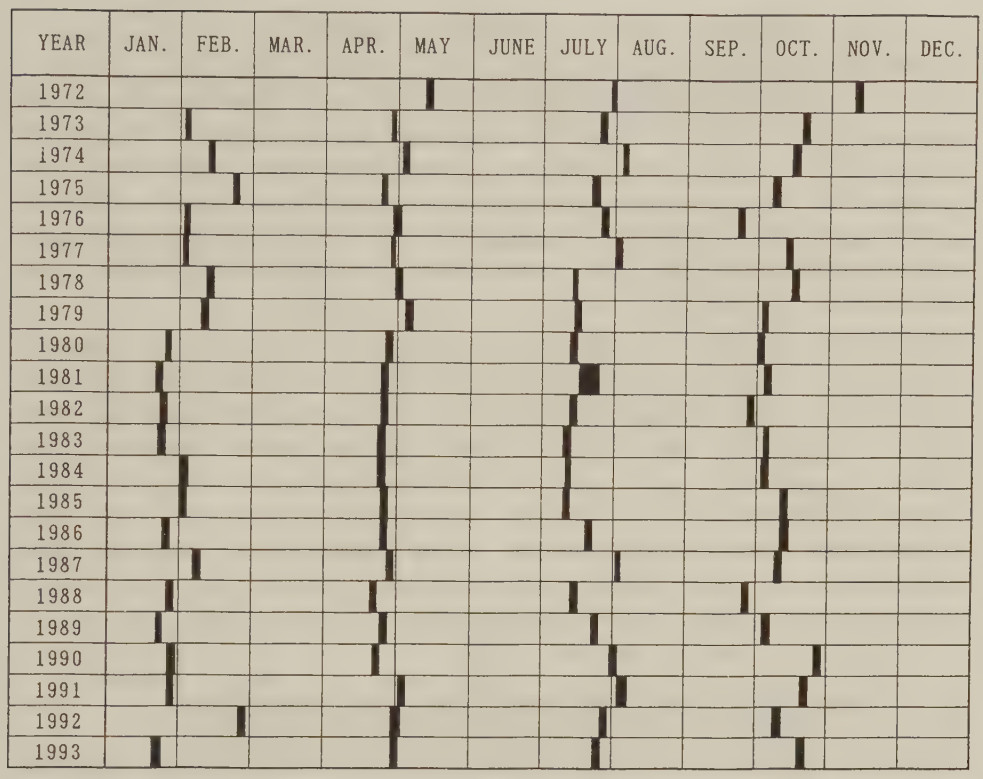

Fig. 2. Periods of each observations. The observation in autumn 1972 was carried out a month later than the mean observation period in autumn, therefore its data is not included in the analysis.

have been made on board the research vessel Chofu-Maru of the Nagasaki Marine Observatory. The observations in winter 1987 and in winter 1992 were carried by the research vessel Ryofu-Maru, the Japan Meteorological Agency.

Hydrographic observation data from the spring in 1973 to the winter in 1987 were obtained with Nansen bottles and reversing thermometers. Salinity was determined with the Inductively Coupled Salinometer (Auto-Lab Industries PTY. LTD.). Since the spring of 1987, hydrographic observations have been made by using a CTD (Neil Brown Mark III), conductivity sensor of which was calibrated with the AUTOSAL 8400A (Guildline Instrument LTD.).

Geostrophic volume transports were calculated referring to the 700×10^4 Pa (700 dbar) surface for four seasons from 1973 to 1993. In the region along the continental slope, water temperature and salinity were extrapolated subjectively into the sea bottom domain, and the northeastward currents flux summed up between PN-1 to PN-5 was regarded as the volume transports of the Kuroshio. (NAGASAKI MARINE OBSERVATORY, 1991)

3. Seasonal variation of water temperature and salinity

3.1 Analysis of variance

FUJIWARA *et al.* (1987) and TAKANO *et al.* (1985) reported that the seasonal variation of water temperature and salinity below 200m depth of the Kuroshio region is smaller than those in the surface layer. An analysis of variance (see Appendix) for four season was carried out in the entire of the PN section to investigate objectively whether seasonal variation is significant or not, compared with short-term (1 – 3 year period) variations and interannual variations. Results are shown in Fig. 3. The regions where seasonal variation is significant to the 95% confidence level are shaded in the figure.

The seasonal variation of water temperature is significant in the layer shallower than 125m at all stations (Fig. 3(a)). Furthermore, although the previous studies showed that a seasonal variation in the intermediate layer of the Kuroshio region is small, another significant region exists in the layer deeper than 500m at PN-1 and in the layer between 200m and 500m at PN-2.

As for salinity, seasonal variation is large in the layer shallower than 75m – 125m depth at almost all the stations (Fig. 3(b)). However, seasonal variation near the bottom at PN-8 on the continental shelf is small compared with short-term and interannual variations. Seasonal variation is also remarkable in the layer between depths of 250m and 600m from PN-1 to PN-3 similar to the results of water temperature.

3.2 Vertical section of water temperature

According to an analysis of variance, the regions where the seasonal variation is significant exist in the layer deeper than 200m depth as well as in the layer shallower than 200m depth. The details of seasonal variation in the layer deeper than 200m depth and the mean oceanic condition compared with FUJIWARA *et al.* (1985) are discussed by using the seasonal mean vertical section and its anomalies from the annual mean for all of the seasons. The distributions of mean water temperature along the section PN for four seasons are shown in Figs. 4(a), 5(a), 6(a) and 7(a). Figs. 4(b), 5(b), 6(b) and 7(b) shows seasonal anomalies from the mean of all seasons. In the layer deeper than 200m depth, the area of positive anomaly greater than +0.2°C are hatched and the area of negative anomaly exceeding than –0.2°C are shaded.

Winter (Fig. 4); Water temperature is vertically uniform as a result of the strong mixing from PN-6 to PN-9 over the continental shelf. A warm core corresponding to the Kuroshio is observed in shallower layer than 100m depth from PN-3 to PN-3'. Sea surface temperature ranges from 13.6°C at PN-9 to 22.4°C at PN-3'. In the layer shallower than 600m depth from PN-1 to PN-2, the thermocline is slightly climbing up towards Okinawa corresponding to the Kuroshio counter current. In the layer deeper than 200m depth, positive anomalies greater than +0.2°C are found in the 200m depth at PN-2, in the 500m depth at PN-3 and in the layer between depths of 200m and 250m from PN-3' to PN-4.

Spring (Fig. 5); Over the continental shelf, water temperature in spring is nearly the same with winter throughout the surface layer while it decreases considerably in the bottom layer. Water temperature in the layer shallower than 50m – 100m depth becomes higher than winter

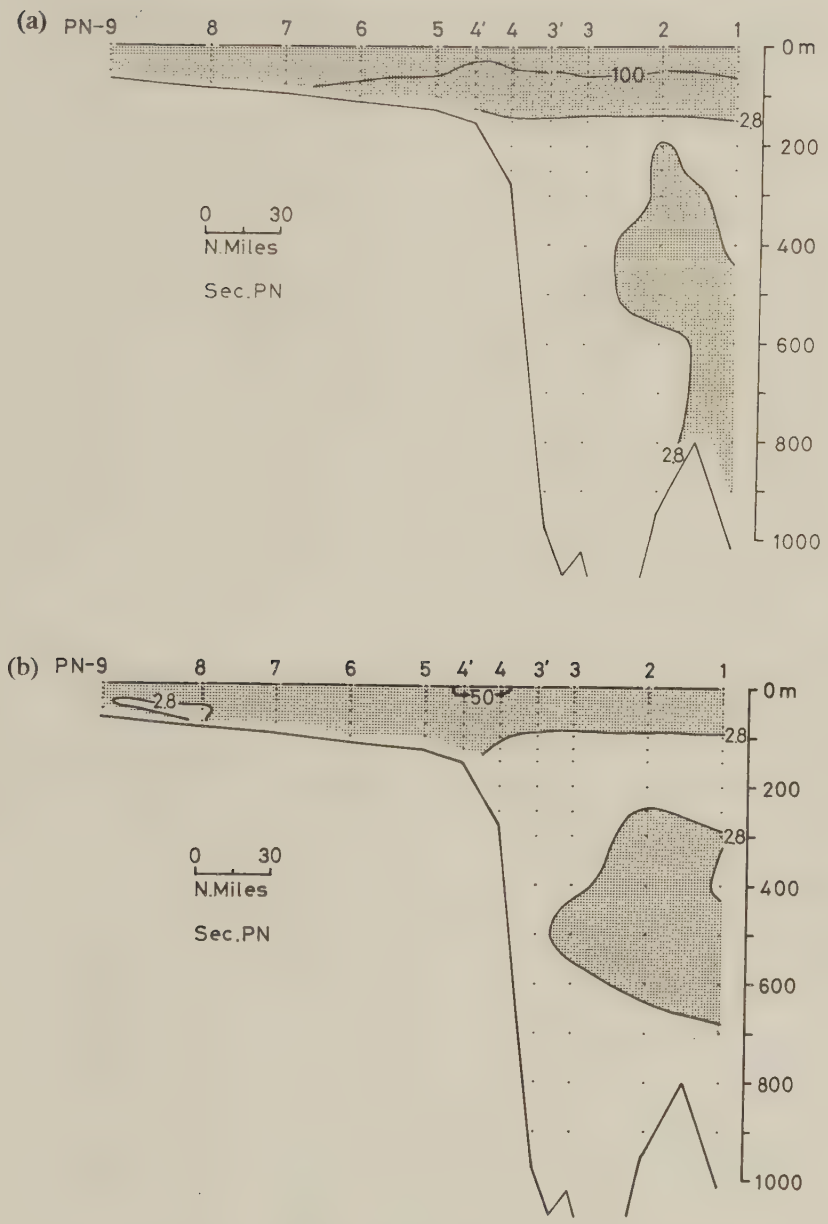

Fig. 3 Results of an analysis of variance for water temperature (a) and for salinity (b). The regions where the F-value is greater than 2.8 are shaded, corresponding to regions where the seasonal variation is significant to the 95% confidence level.

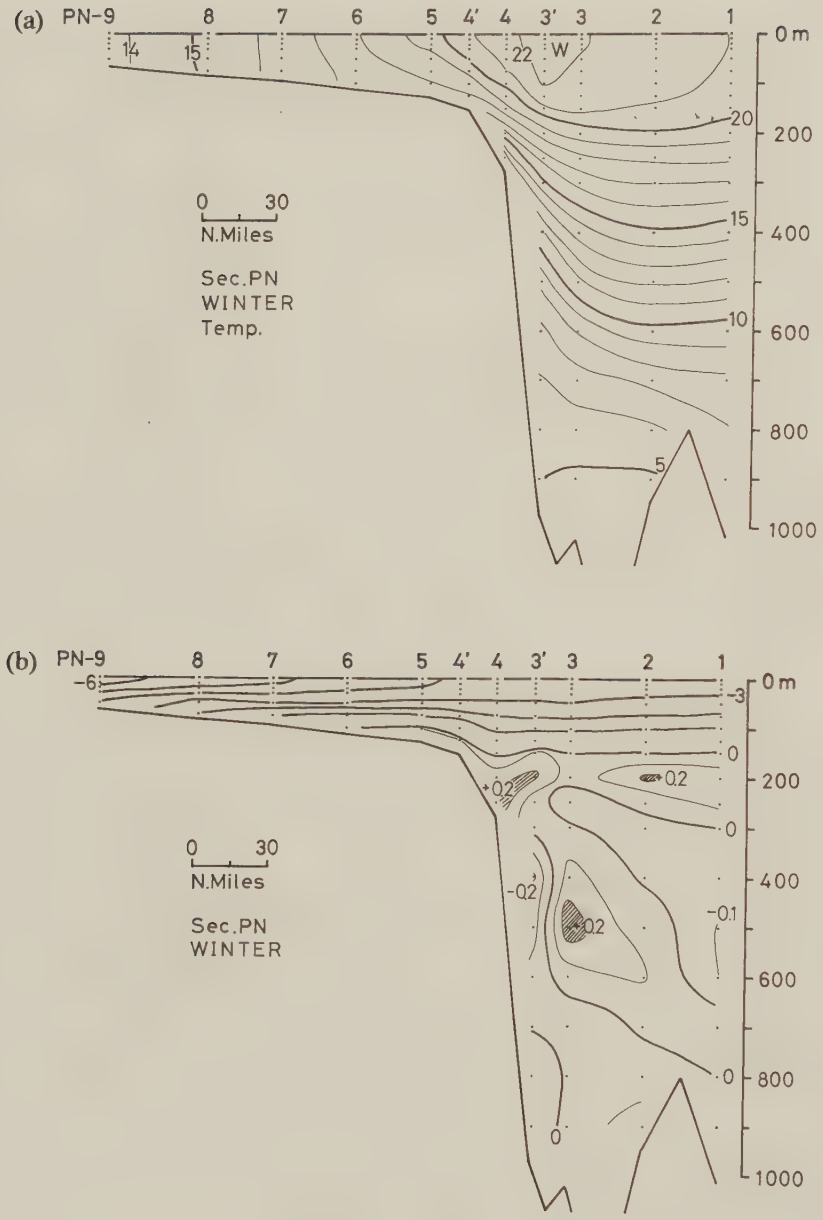

Fig. 4 Mean water temperature (°C) on the section PN (a), and water temperature anomalies of the seasonal means referred to the mean of all seasons (b), in winter. Below 200m, the positive anomaly area greater than +0.2°C is hatched and the negative anomaly area greater than –0.2°C is shaded.

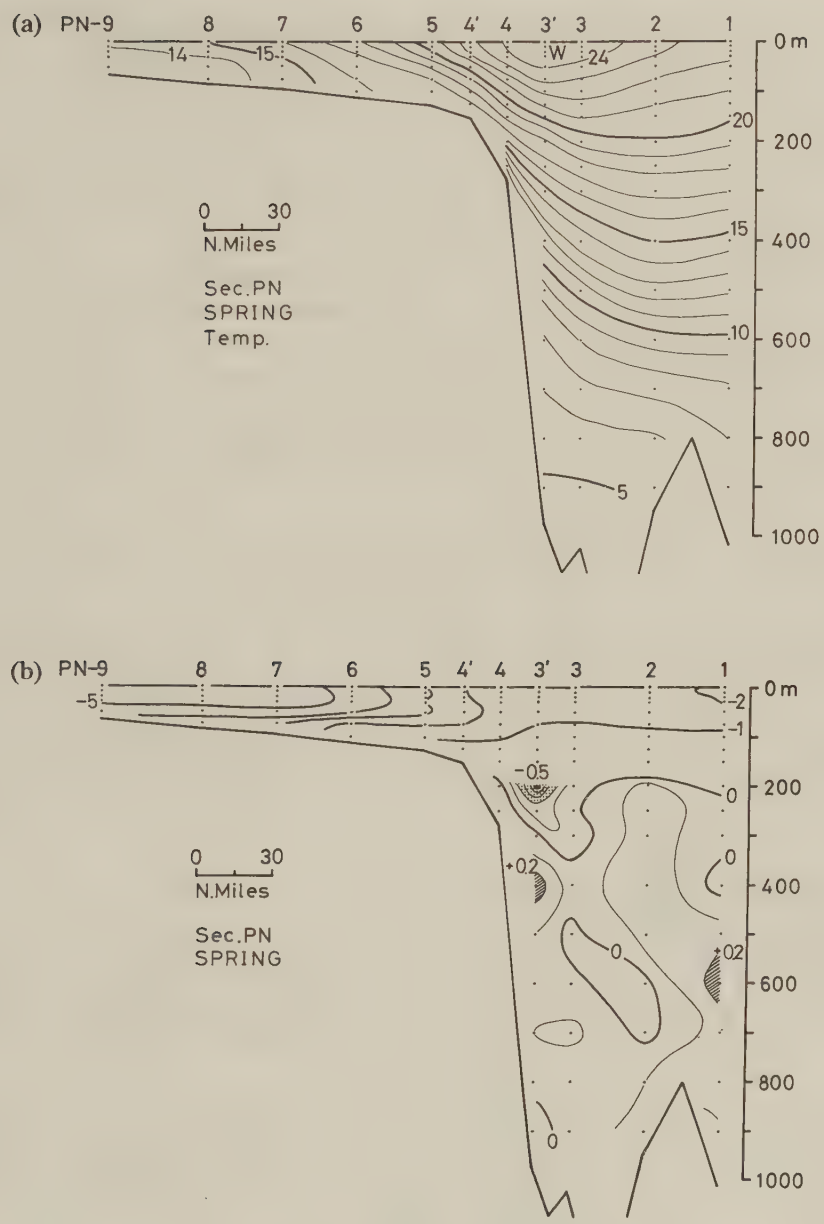

Fig. 5 As in Fig. 4 but in spring.

at the Kuroshio region from PN-1 to PN-5. The warm core (>24°C) is observed above 50m depth from PN-3 to PN-4. The thermal structure of the Kuroshio counter current, i.e. the shoal of isotherm toward Okinawa, is found in the layer where water temperature is higher than 12°C between PN-1 and PN-2. The inclination of the isotherm around PN-3 corresponding to the Kuroshio is flat in comparison with winter. Below 200m depth, water temperature anomalies are higher than +0.2°C in the 600m depth at PN-1 and in the 400m depth at PN-3', and negative deviation is over than –0.5°C in the 200m depth at PN-3'.

Summer (Fig. 6); A clear thermocline exists over the continental shelf. Water temperature above 125m depth becomes high in comparison with spring. Sea surface temperature over the continental shelf becomes nearly the same with the Kuroshio region, and ranges from 28°C to 29°C at all stations. The thermal structure in the intermediate layer of the Kuroshio is similar to that in winter and in spring. Water temperature anomalies below 200m depth are higher than +0.2°C in the layer between depths of 300m and 500m from PN-1 to PN-2. The area where anomalies are higher than +0.2°C is wider than other seasons. Negative anomaly of –0.5°C is found in the 250m depth at PN-4.

Autumn (Fig. 7); Over the continental shelf, the vertical mixing occurs and water temperature becomes vertically uniform in the top of 30m or 50m. Water temperature anomalies below 200m depth is negative in a wide area, namely the layer from 200m to 600m from PN-1 to PN-3, especially in the 200m depth and in the layer from 400m depth to 500m depth at PN-2 where negative anomalies are greater than –0.4°C. Except for the data of autumn, the seasonal variation below 200m depth is not significant in an analysis of variance for three seasons (figure not shown). The decrease of water temperature in autumn at the intermediate layer of the Pacific side of the Kuroshio is largest at PN-2, which corresponds to the boundary between the Kuroshio and the Kuroshio counter current.

3.3 Vertical section of the salinity

The distributions of mean salinity on the section PN for four seasons are shown in Figs. 8(a), 9(a), 10(a) and 11(a). Figs. 8(b), 9(b), 10(b) and 11(b) shows seasonal anomalies from the mean of all seasons. In the layer deeper than 200m depth, the area of positive anomaly greater than +0.02 are hatched and the area of negative anomaly exceeding than –0.02 are shaded.

Winter (Fig. 8); Salinity marks its maximum among the four seasons in winter in the surface layer. The layer of salinity maximum above 34.8 exists around the 200m depth from PN-1 to PN-3' and extends to the sea surface at PN-1, which is thicker than other seasons. Below 200m depth the area where the anomaly is higher than +0.02 is seen only in the 250m depth at PN-4.

Spring (Fig. 9); The halocline is formed near the sea surface from PN-5 to PN-9 over the continental shelf. The salinity maximum area above 34.8 distributes in the layer from 100m depth to 250m depth from PN-1 to PN-3'. Below 200m depth, negative anomaly is greater than –0.03 in the 200m depth at PN-3'.

Summer (Fig. 10); The halocline becomes remarkable over the continental shelf. Salinity above

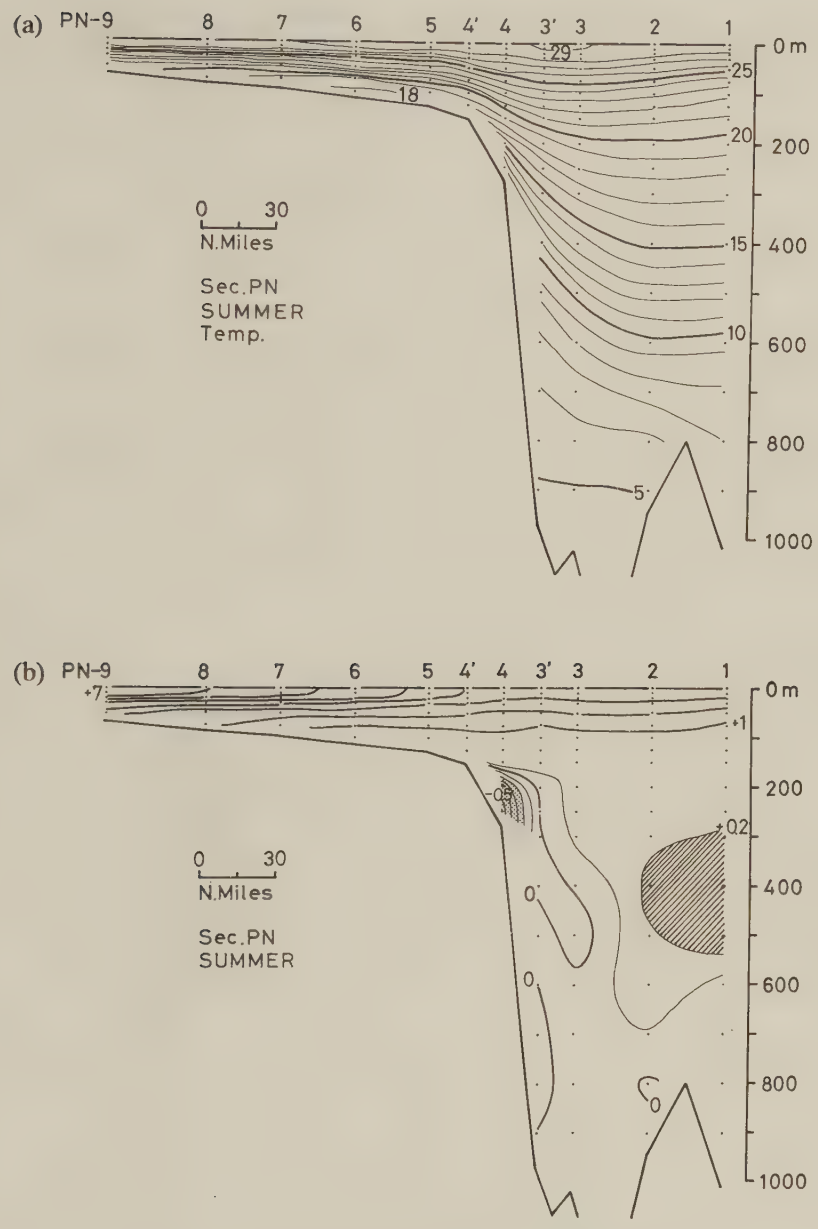

Fig. 6 As in Fig. 4 but in summer.

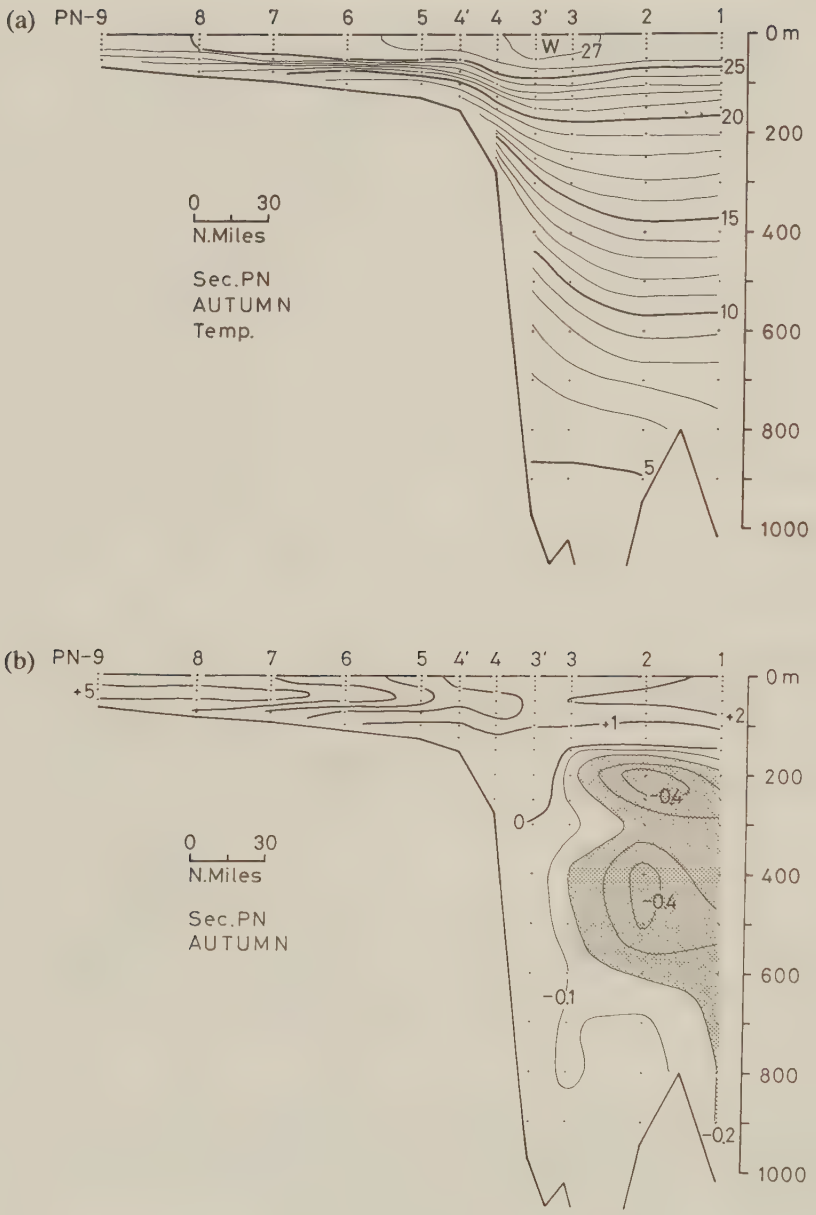

Fig. 7 As in Fig. 4 but in autumn.

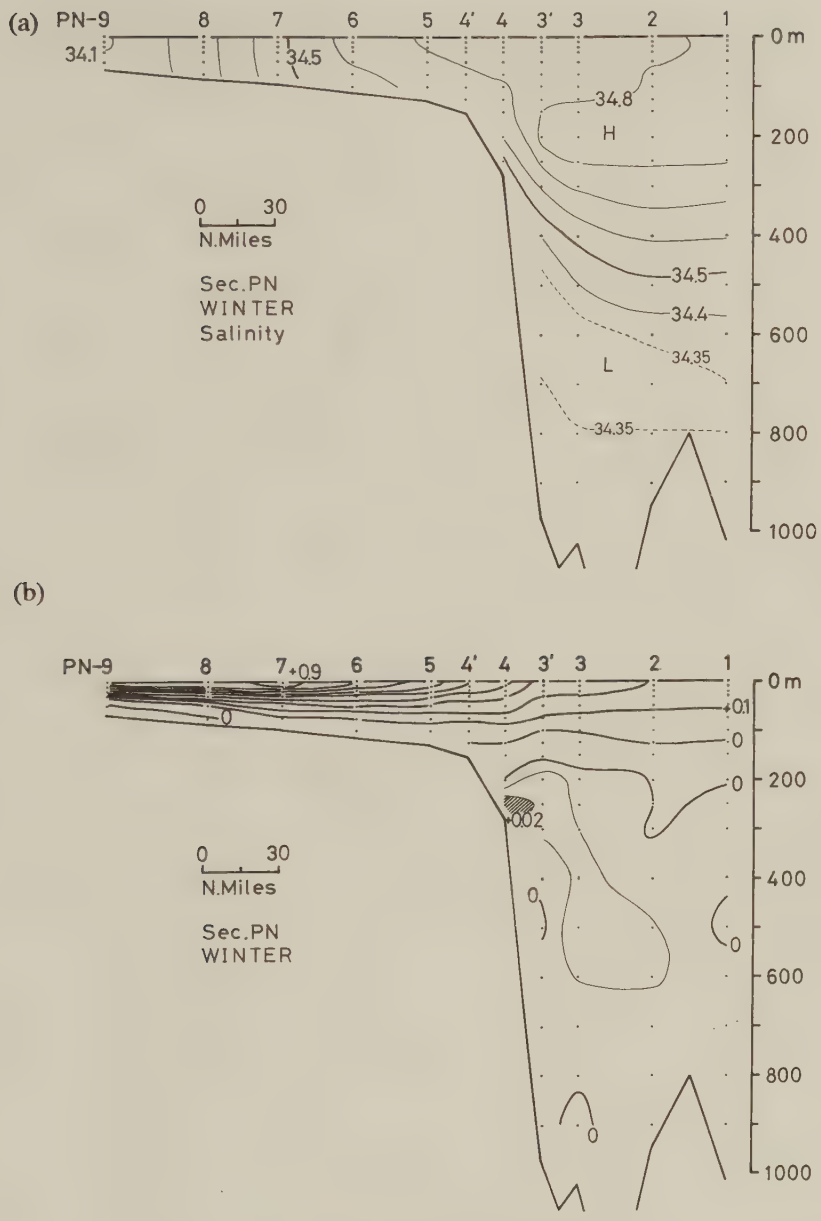

Fig. 8 Mean salinity (psu) on the section PN (a), and salinity anomalies of the seasonal means referred to the mean of all seasons (b), in winter. Below 200m, the positive anomaly area greater than +0.02 psu is hatched and the negative anomaly area greater than –0.02 psu is shaded.

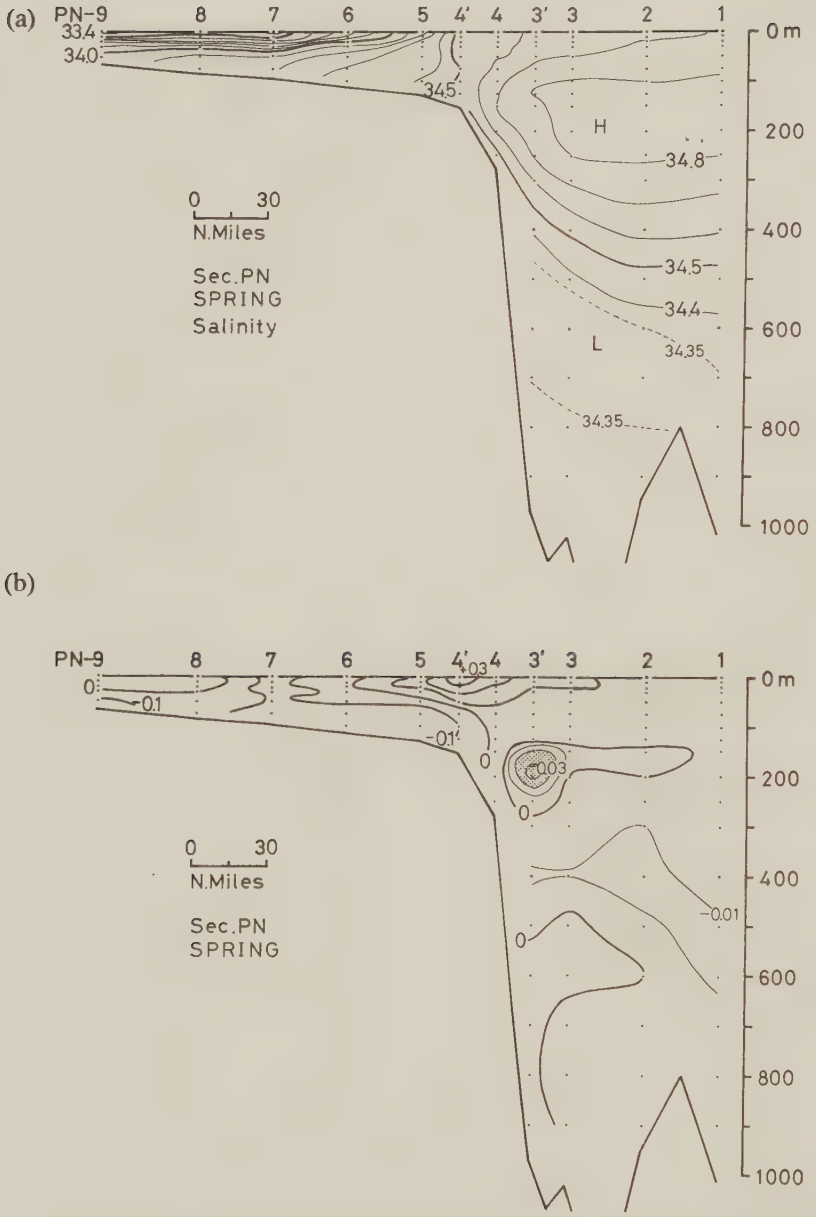

Fig. 9 As in Fig. 8 but in spring.

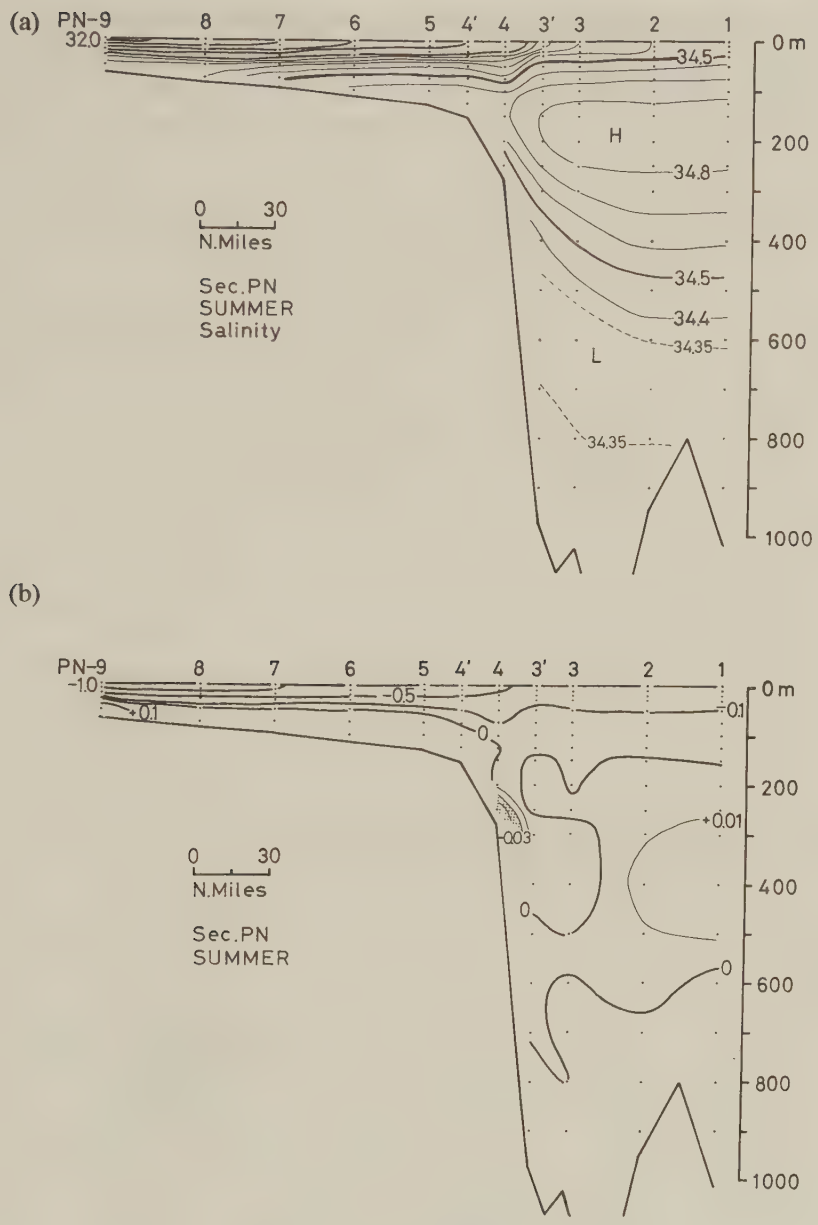

Fig. 10 As in Fig. 8 but in summer.

the halocline is lowest throughout the year while salinity below the halocline is about the same or a little high in comparison with other seasons. Below 200m depth, negative anomaly is greater than –0.02 in the 250m depth at PN-4.

Autumn (Fig. 11); The layer of salinity maximum above 34.8 distributes in the layer between

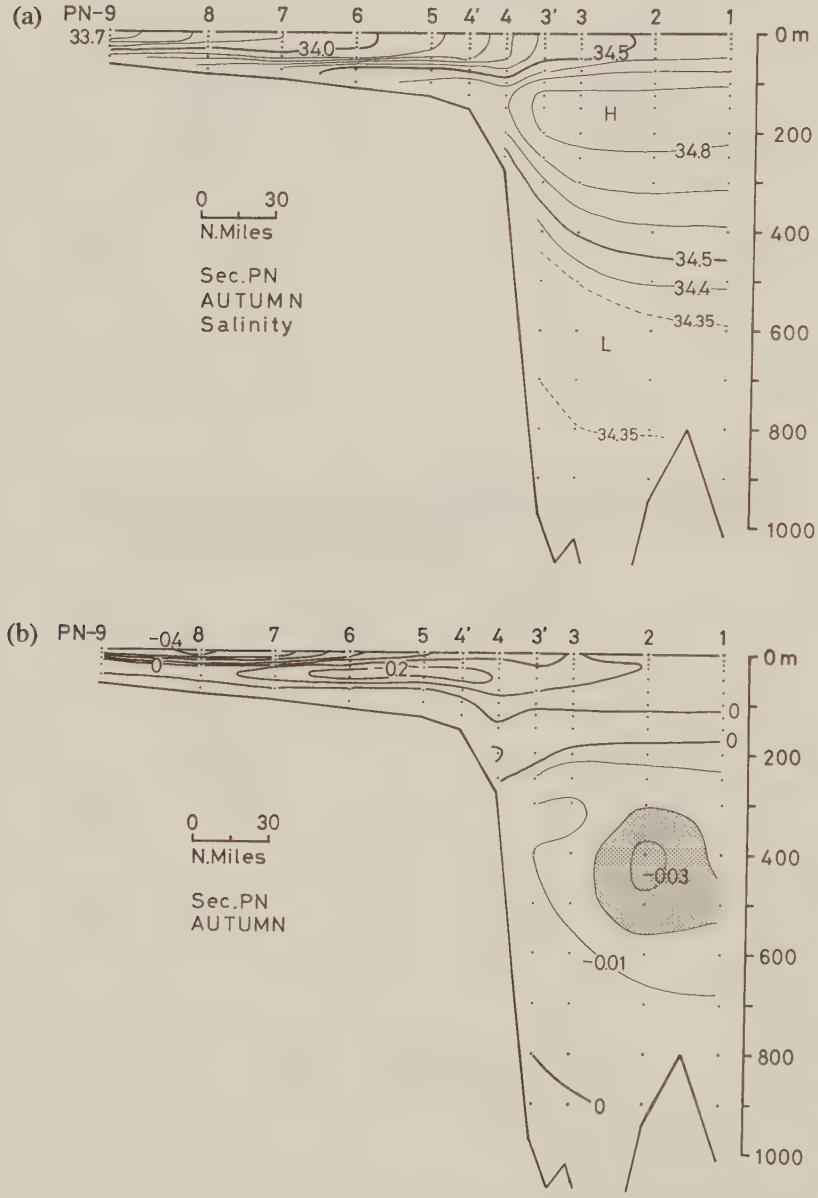

Fig. 11 As in Fig. 8 but in autumn.

depths of 125m and 200m depth from PN-1 to PN-3', which is thinnest throughout the year. The salinity minimum layer below 34.35 is a little thicker than those in the other seasons, and salinity at the 600m depth is less than 34.35 from PN-1 to PN-2. Salinity anomalies below 200m depth are lower than –0.02 in the wide area around the 400m and 500m depth from PN-1 to PN-2 as well as the decrease of water temperature in the intermediate layer around PN-2. Except for the data of autumn, a seasonal variation of salinity below 200m depth is not significant in an analysis of variance for three seasons, similar to water temperature.

4. Seasonal variation of the Kuroshio volume transport

Geostrophic volume transports of the Kuroshio from 1973 to 1993 at each cruise and their seasonal means are shown in Table 1. The volume transport of the winter in 1974 is extremely

Table 1 Geostrophic volume transports (Sv = $10^6 m^3 sec^{-1}$) with their seasonal mean, annual mean and standard deviation. Volume transport of the winter in 1974 is not included in the analysis.

Year	Winter	Spring	Summer	Autumn	Annual Mean
1973	27.0	22.8	24.2	19.0	23.3
1974	6.7*	21.8	24.8	18.3	21.6
1975	19.3	24.1	29.6	20.2	23.3
1976	28.9	27.3	29.8	20.8	26.7
1977	18.2	33.1	29.0	24.9	26.3
1978	26.6	23.0	23.1	22.5	23.8
1979	25.0	25.2	24.6	20.5	23.8
1980	22.4	27.5	28.2	22.9	25.3
1981	31.4	31.4	27.3	25.8	29.0
1982	27.3	21.3	25.0	26.3	25.0
1983	25.9	22.9	21.6	24.4	23.7
1984	27.1	26.7	26.9	23.2	26.0
1985	25.8	26.7	29.7	22.4	26.2
1986	35.0	30.9	20.7	26.9	28.4
1987	31.7	21.6	25.2	24.0	25.6
1988	29.8	27.4	29.3	27.3	28.5
1989	21.8	22.6	25.7	20.0	22.5
1990	21.3	26.3	31.2	23.4	25.6
1991	29.1	28.3	29.5	19.6	26.6
1992	25.7	26.1	30.6	24.1	26.6
1993	27.3	20.2	26.9	28.7	25.8
Total	526.6	537.2	562.9	485.2	2111.9
Number	20	21	21	21	83
Mean	26.3	25.6	26.8	23.1	25.4
St.dev.	4.2	3.5	3.0	2.9	3.7

small and was not treated in the analysis. The seasonal means, the overall mean and seasonal standard deviations of the volume transport are also shown in Fig. 12.

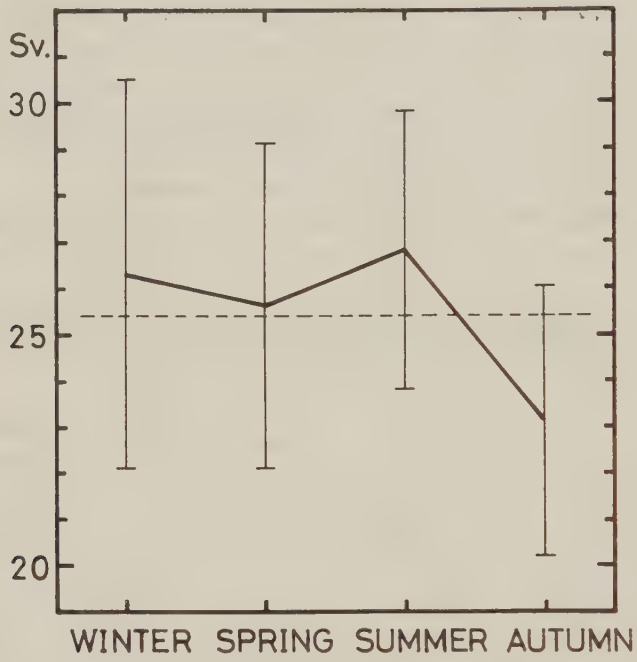

Fig. 12 Geostrophic volume transport (Sv = $10^6 m^3 sec^{-1}$) of seasonal mean (thick line), total mean (dashed line) and standard deviation (thin vertical line).

The maximum volume transport of 35.0 Sv is observed in the winter, 1986 and the minimum volume transport of 18.2 Sv in the winter, 1977. Seasonal mean volume transports for the years of 1973–1990 are 26.3 Sv in winter, 25.6 Sv in spring, 26.8 Sv in summer and 23.1 Sv in autumn, respectively. As for the volume transport of the Kuroshio, its interannual variation is reported to be more remarkable than seasonal variation (KAWABE, 1988), and short-term variation is also observed (FUJIWARA *et al.*, 1987; ICHIKAWA and BEARDSLEY, 1993). Interannual and short-term variations contribute to the seasonal standard deviation of volume transports, which is largest in winter, that is 4.2 Sv.

Various studies report that volume transport or current speed of the Kuroshio in the East China Sea is small in autumn and large in spring or summer (i.e., KAWABE, 1988; ICHIKAWA and BEARDSLEY, 1993). According to an analysis of variance in the present study, the F-value is 4.76 and the 95% confidence level is 2.72 among all of the four seasons. On the other hand, the F-value is 0.61 and the 95% confidence level is 3.15 among the three seasons except for autumns. Therefore, the seasonal variation of volume transport is significant, that is due to the decrease of volume transport in autumns.

It seems that such seasonal variation of volume transport is affected by some variation of water temperature and salinity field, and an examination is tried by the following method. Geostrophic volume transports calculated from the seasonal mean field of water temperature and salinity are shown in Table 2. Due to using smoothed water temperature and salinity distribution without extrapolation into the continental slope, the volume transports are smaller than the ones shown in Table 1. However, the volume transports obtained with this method still show the relative seasonal variation. Volume transports of case 1 in Table 2 are calculated from seasonal means. Volume transports of case 2 are calculated by replacing the data below

Table 2 Geostrophic volume transports calculated by seasonal mean of water temperature and salinity. Volume transports of case 1 are the results calculated from each seasonal mean. Volume transports of case 2 are calculated by replacing the data below 200m with the mean values of all seasons. On the other hand, volume transports of case 3 are calculated replacing the data above 150m with the mean value of all seasons.

	Winter	Spring	Summer	Autumn	Annual Mean
Case 1	17.8	17.4	18.6	15.5	17.3
Case 2	17.2	17.4	17.4	17.1	17.3
Case 3	17.9	17.2	18.4	15.7	17.3

200m depth with the annual mean values for estimating the contribution of the surface layer to the seasonal volume transport variation. Volume transports of case 3 are calculated by replacing the data above 150m depth with the annual mean value for estimating the contribution of the seasonal variation in the intermediate layer. Volume transports of case 3 are close to case 1, whereas, the seasonal variation in case 2 is only 0.3 Sv at the most. Therefore, the seasonal variation of the geostrophic volume transports is caused by the seasonal variation of water temperature and salinity in the intermediate layer.

In autumn, not only the decrease of water temperature but the decrease of salinity in intermediate layer of the Pacific side of the Kuroshio is found. Table 3 shows the seasonal means of sigma-t at the 400m depth of PN-3' – PN-1, where the decrease of water temperature and salinity in autumn is large. Sigma-t at the 400m depth is large in the continental slope domain (PN-3') and decreases in the offshore side of the Kuroshio. Sigma-t is more influenced by the decrease of water temperature than by the decrease of salinity in autumn, resulting in the sigma-t increase from PN-1 to PN-3. The horizontal gradient of density becomes small in autumn, and the geostrophic volume transport decreases.

An analysis by using T-S diagrams is carried out to examine the cause of the decreases of water temperature and salinity in the intermediate layer. Fig. 13 shows the T-S diagram of the seasonal mean at PN-2, where the decrease of water temperature and salinity are largest

Table 3 Seasonal means of sigma-t (kgm^{-3}) at the 400m depth of PN-3' – PN-1.

	PN-3'	PN-3	PN-2	PN-1
WINTER	26.35	25.92	25.72	25.74
SPRING	26.27	25.93	25.69	25.75
SUMMER	26.31	25.93	25.67	25.69
AUTUMN	26.30	25.97	25.78	25.77
MEAN	26.31	25.94	25.72	25.74

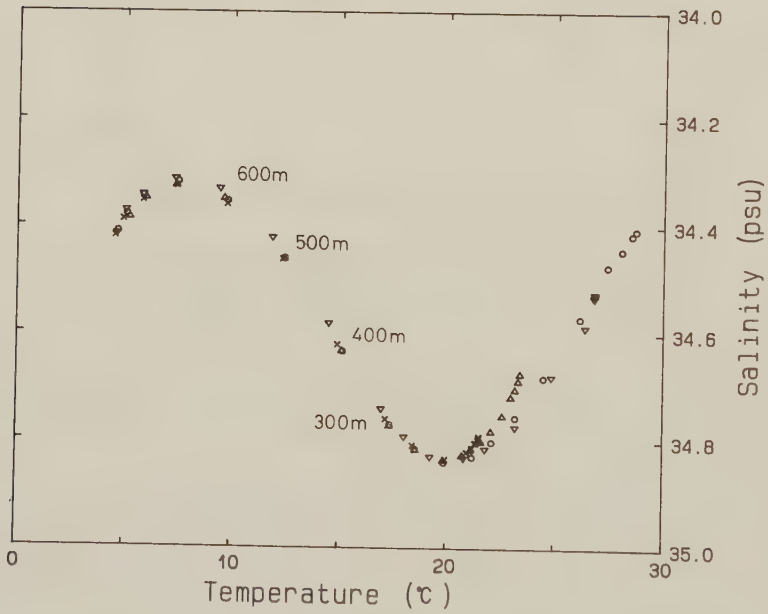

Fig. 13 T-S diagram of the seasonal mean at PN-2. Data in winter, spring, summer and autumn are marked by ×, Δ, ○ and ▽.

of all stations. The plots of standard depth layers from 300m to 600m depth shift to the low temperature and low salinity side only in autumn, according to the decrease of water temperature and salinity in autumn. Nevertheless, the autumn plots are still within the T-S relationship of the other seasons. Therefore, the drop of water temperature and salinity in autumn is not due

to the replacement of water mass but to the upward shift of the thermocline and halocline in the intermediate layer.

WHITE (1978) analyzed the distribution of water temperature at 200m depth in the North Pacific using the 30,000 XBT records collected from 1968 to 1974, and showed that water temperature south of 35°N is warmer in spring and early summer, and colder in fall and early winter in the western midlatitude North Pacific. LIE and ENDOH (1991) analyzed bimonthly mean temperature in the west North Pacific using the 200,000 BT data collected from 1964 to 1983, and showed that the deviation of water temperature from the annual mean south of 32°N at the 200m and 400m depths is positive in March – April but changes sign in September – October. It seems that the rise of thermocline and halocline in the East China Sea is coherent with those in the subtropical North Pacific in autumn. Nevertheless, the deepening of thermocline and halocline is not found in the East China Sea in spring or in summer.

5. Long-term trend of water temperature and salinity

Time-series of water temperature and salinity are examined for understanding long-term variabilities. For an example, Fig. 14 shows time-series of water temperature at depths of the 100m, 300m and 600m at PN-3 from 1972 to 1993. Anomalies from seasonal means are used in order to eliminate seasonal variation. Time-series of salinity is shown in Fig. 15, similar to Fig. 14.

In the time-series at the 600m depth where the short-term variation is relatively small, negative anomalies of water temperature is remarkable before 1980 and negative anomalies of salinity are found after 1987. Though there is a possibility that such variability is a part of variation with ten or several ten-year periods, the trends of time-series in both water temperature and salinity are examined as one of the most simple estimation methods in the present study.

A t-test is carried out to confirm the statistical significance of the trends. Table 4-1 shows trends of temperature that are significant by the t-test. The area where trends are not significant are shaded in the table, and the area where no test is carried out due to lack of data is left blank. Trends of salinity is shown in Table 4-2 in a similar way. There are positive temperature trends in the layer from 800m to 900m at PN-1 and in the layer from 400m to 600m from PN-2 to PN-3. Negative trends are seen in the layer from 30m to 150m from PN-3 to PN-3'.

SHIRAISHI *et al.* (1994) found that the sea surface temperature in the northern part of the East China Sea increases rapidly in the rate of 0.5°C per 10 years since 1970 by using sea surface temperature data obtained from 1953 to 1991. However, no significant trend is found in this t-test. There are negative salinity trends in the layer deeper than 500m depth from PN-1 to PN-3', and positive trends in the layer above 250m from PN-1 to PN-3, in the layer from 10m to 50m at PN-4, in the layer above 10m depth at PN-5 and in the sea surface at PN-9. Trends in the layer above 250m depth from PN-1 to PN-2 are significant only in salinity. The largest trends in the intermediate layer of temperature and salinity are 0.03°C/year and –0.0025 psu/year, respectively. This means that water temperature has increased 0.6°C while salinity has decreased 0.05 psu during the past 20 years in the intermediate layer of the Kuroshio.

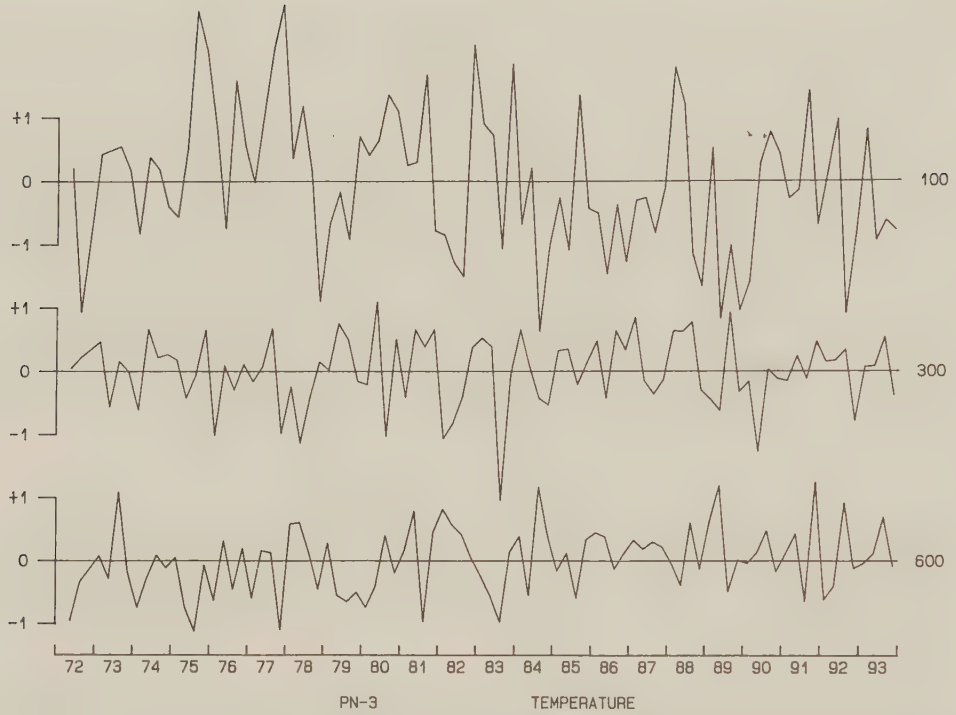

Fig. 14 Time-series of water temperature in the 100m, 300m and 600m depths at PN-3 from 1972 to 1993. Data used are anomalies from seasonal mean in order to eliminate seasonal variation.

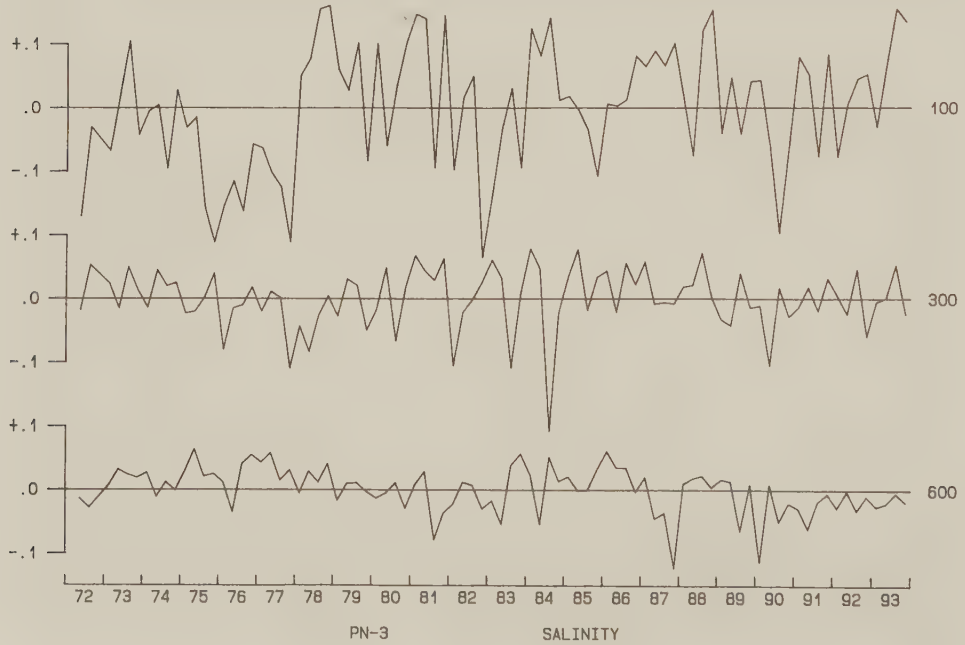

Fig. 15 As in Fig. 14 but for salinity.

Table 4-1 Trends of temperature in the period from 1972 to 1993. Numerical values shows the significant area, the shaded value is not significant and the area where no test is carried out due to lack of data is left blank.

(unit ℃/year)

	PN-9	PN-8	PN-7	PN-6	PN-5	PN-4'	PN-4	PN-3'	PN-3	PN-2	PN-1
0m	-0.019	-0.017	-0.008	-0.030	-0.018	-0.004	-0.017	-0.031	-0.026	-0.005	-0.019
10	0.000	-0.005	0.004	-0.012	-0.005	-0.004	-0.011	-0.035	-0.017	0.001	-0.016
20	0.008	-0.001	-0.003	0.001	0.003	0.011	-0.006	-0.042	-0.021	0.006	-0.019
30	0.002	-0.010	0.007	-0.005	0.021	0.024	-0.000	-0.044	-0.033	-0.004	-0.014
50	-0.010	0.009	-0.015	0.005	0.003	0.023	0.008	-0.053	-0.040	-0.005	-0.005
75		0.002	0.011	0.023	0.021	-0.003	-0.005	-0.052	-0.043	-0.007	-0.005
100				0.032	0.039	-0.002	-0.005	-0.070	-0.049	-0.022	-0.004
125						0.024	-0.008	-0.078	-0.047	-0.033	-0.007
150							-0.012	-0.064	-0.039	-0.021	-0.009
200							-0.022	-0.028	-0.027	-0.014	-0.009
250							-0.018	0.000	0.005	-0.015	-0.001
300								0.002	0.002	-0.005	0.005
400								0.030	0.028	0.021	0.017
500								0.022	0.032	0.030	0.019
600								-0.002	0.023	0.029	0.013
700								-0.013	0.008	0.006	0.010
800									0.001	0.001	0.009
900									0.006		0.011
1000											

Table 4-2 As in Table 4-1 but for salinity.

(unit psu/year)

	PN-9	PN-8	PN-7	PN-6	PN-5	PN-4'	PN-4	PN-3'	PN-3	PN-2	PN-1
0m	0.0323	0.0025	-0.0017	0.0066	0.0215	-0.0006	0.0081	0.0044	0.0055	0.0084	0.0062
10	0.0141	0.0034	0.0049	0.0059	0.0168	-0.0013	0.0091	0.0026	0.0070	0.0078	0.0063
20	0.0055	-0.0034	0.0021	0.0057	0.0101	-0.0028	0.0100	0.0021	0.0073	0.0070	0.0065
30	0.0075	-0.0059	0.0022	0.0044	0.0087	-0.0051	0.0090	0.0011	0.0083	0.0067	0.0062
50	0.0050	0.0008	0.0032	0.0053	0.0065	-0.0059	0.0087	0.0003	0.0079	0.0065	0.0051
75		-0.0019	-0.0004	-0.0001	0.0024	-0.0058	0.0042	-0.0007	0.0048	0.0041	0.0039
100				-0.0020	0.0034	0.0011	0.0004	-0.0017	0.0043	0.0038	0.0023
125						0.0023	0.0004	0.0018	0.0035	0.0033	0.0020
150							-0.0003	-0.0005	0.0027	0.0022	0.0020
200							-0.0004	-0.0008	0.0013	0.0019	0.0019
250							-0.0024	0.0002	0.0006	0.0009	0.0015
300								-0.0007	0.0001	0.0005	0.0010
400								-0.0012	0.0000	0.0009	0.0006
500								-0.0021	-0.0006	0.0002	-0.0002
600								-0.0025	-0.0020	-0.0010	-0.0009
700								-0.0023	-0.0024	-0.0025	-0.0015
800									-0.0018	-0.0017	-0.0017
900									-0.0014		-0.0014
1000											

6. Summary

This study deals with the vertical structures of temperature and salinity as well as the geostrophic volume transport of the Kuroshio and analyzes the seasonal variation and the long-term trend along the PN-line in the East China Sea. The results are summarized as follows:

(1) The characteristics of seasonal variation in the layer shallower than 200m depth are almost consistent with the previous studies (TAKANO *et al.*, 1985; FUJIWARA *et al.*, 1987).

(2) According to an analysis of variance, water temperature and salinity in autumn decrease in the intermediate layer of the Pacific side of the Kuroshio. The drop of water temperature and salinity in autumn is not due to the replacement of water mass but to the upward shift of the thermocline and halocline in the intermediate layer.

(3) In autumn, the geostrophic volume transport of the Kuroshio decrease in response to the shoal of the thermocline and halocline in the intermediate layer of the Pacific side of the Kuroshio. This decrease of the Kuroshio volume transport in autumn is statistically significant by an analysis of variance.

(4) In the intermediate layer of the Kuroshio and in some other layers, significant long-term trends are found in both water temperature and salinity. In the intermediate layer of the Kuroshio, water temperature increased 0.6°C but salinity decreased 0.05 psu during the past 20 years.

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Appendix

Analysis of variance (KAWADA *et al.*, 1977)

An analysis of variance is similar to a test of the difference between various means. A test of the following hypothesis is carried out when n_i(i=1,2,...,k) samples are extracted from populations where k is the number of groups (seasons in this study). The hypothesis is $m_1=m_2=...=m_k$ where m_i is the mean of the "i" group population. Then, two estimators of variance are introduced.

$$\omega_1 = \sum_{i=1}^{k} n_i (\overline{x_i}-\overline{x})^2,\ \omega_2 = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (x_{ij}-\overline{x_i})^2$$

where x_{ij} are value of samples, x_i are group means of samples, x is the total mean and n_i are numbers of samples within the "i" group. ω_1 indicates a variance of each group mean and become larger when intergroup (seasonal) variation increases. ω_2 indicates a variance within

each group and become larger when intragroup variations increases. To confirm whether intergroup (seasonal) variation is significant or not, the F-value is calculated by using the two estimators of variance, ω_1 and ω_2.

$$F = \frac{(n-k)\,\omega_1}{(k-1)\,\omega_2}$$

where n is the total number of samples. The F-value agrees with the F-distribution with k-1, n-k degrees of freedom. The hypothesis is rejected if the F-value is larger than the value of F(ε, k-1, n-k) where 1-ε is a confidence level. Therefore, an intergroup (seasonal) variation is significant compared with intragroup (short-term and interannual) variation in the case of F-value > F(ε, k-1, n-k). On the other hand, an intergroup variation is not significant in the case of F-value < F(ε, k-1, n-k).

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東シナ海定線における水温・塩分と黒潮流量の季節変動および水温・塩分の長期トレンド

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(長崎海洋気象台)
(現神戸海洋気象台)

長崎海洋気象台では1972年春季より、東シナ海のPN線での海洋観測を各季節毎に実施している。それらの観測資料に基づき、水温・塩分および黒潮の地衡流量における季節変動および長期トレンドに関する解析を行った。

分散分析によると黒潮より沖合いの太平洋側の中層では、水温および塩分は秋季のみ低下する。また、秋季の黒潮流量も減少する。この秋季の水温・塩分低下は、水塊が替るのではなく、水温・塩分躍層の上昇によって起きる。

水温・塩分の長期的な変動では、黒潮中層を始めとして有意なトレンドがみられる。黒潮中層ではこの20年間で水温が最大0.6°C上昇し、塩分は0.05 psu低くなっている。

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Long Term Trends and ENSO Events-related Variability of the Oceanic Conditions on the Vertical Profile along 41°30'N in the Sea South of Hokkaido

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Abstract: Using oceanographic observation data along 41°30'N parallel line over 142°E-147°E from winter 1972 to summer 1994, long term trends and ENSO events-related variability of the oceanic conditions from sea surface to intermediate layer were investigated. Long-term trends have lowering senses in temperature during this period from subsurface to intermediate water. On the other hand, those in salinity have decreasing senses at subsurface layer and increasing senses at intermediate layer, and those in dissolved oxygen are opposite to there in salinity. These trends are resulted from the frequent intrusion of the Oyashio cold waters in the 1980's or later.

Furthermore, variations with a period of 2 – 3 years were found in the Oyashio Intermediate Water. Their variability has close correlations with the indices of the ENSO events (e.g. Sea Surface Temperature in the equatorial Pacific, Suthern Oscillation Index, etc.).

1. Introduction

Sea area east of Honshu is a contact area with the Oyashio which is a part of the Oceanic Subarctic Gyre and the Kuroshio Extension, a part of the Oceanic Subtropical Gyre. The area comprises the Oyashio Front, the Kuroshio Front and an area called their confluenced area or perturbed area. Seas near Hokkaido around the Oyashio Front is considered as the source area of the North Pacific Intermediate Water (e.g., Talley, 1993; Fujimura and Nagata, 1992), and it is suggested that this sea area plays an important role in the global oceanic circulation.

Using oceanographic data around the sea area, various analyses and studies have been done on variations of the oceanic conditions. Ishida and Ogawa (1989) analyzed the data observed by Iwate Prefectural Fisheries Experimental Station from 1961 to 1987. They pointed out the trend of temperature decrease which was statistically significant during this period, and suggested that the First Oyashio Intrusion affected it. Kutsuwada (1992) revealed a decadal scale variability and the trend of temperature decease, and suggested the variations of winds over the sea as a cause of the variations above. Kubo (1992) investigated the distribution of species of diatoms in sea surface water along 41°30'N, and reported that warm water species occupied large area in 1970's when the SST (sea surface temperature) was high, while cold water species occupied large area in 1980's when the SST was low. Kutsuwada (1990) investigated long-term variability

of oceanic and atmospheric condition off Sanriku Coast and reported that the variations with a period of 3.5 years relating to the ENSO events were dominant in this area. SEKINE (1992) pointed out that the strength of the First Oyashio Intrusion had the relationship with global atmospheric circulation such as the ENSO events and related to the PNA Pattern. Furthermore, there were other reports that quasi-bienniel variations were dominant also in the East China Sea (KANEKO and EGUCHI, 1987) and their phases of variations were 8 months later than those in the Eastern Equatorial Pacific (KANEKO *et al.*, 1994).

On the other hand, various numerical experiments of global oceanic circulation have been pointed out that self-inductive oscillations with periods of from several years to several decades are found in the ocean even if external forces from atmosphere are kept constant. Weaver and SARACHIK (1991) as an example, noticed that a decadal oscillation existed and source areas of abyssal water mass in a high latitude moved to change the strength of intrusion of abyssal water mass varied periodically. Numerical experiments by ITOH (1993) showed the existence of an oscillation in salinity with a period around 30 years resulted from the advection in a high latitude.

Oceanographic observations, periodically 4 times a year (every season), have been carried out by the Hakodate Marine Observatory on board the research vessel "Kofu-maru" since 1972 along 41°30'N parallel line south of Hokkaido over 142°E – 147°E (Hakodate Marine Observatory, 1994). The data cover for 22 years.

Until now observed oceanic data obtained from the sea surface to only a depth of 200m have been handled to investigate long-term oceanic variations. We investigated the oceanic variations down to abyssal layer and compared the characteristics with those in the subsurface layer. Moreover, we investigated relationships between time variations of the intermediate layer and those of atmospheric climatologocal conditions. In this study, data observed in this sea area by other research vessels belonging to the Japan Meteorological Agency (JMA) were also used.

The Tsugaru Warm Current traces along the east coast of Northern Honshu during winter and spring, and extends to the sea south of Hokkaido during summer and autumn. The Oyashio extends southward to off Sanriku in spring and recedes to the sea near the coast of Southern Hokkaido (e.g., YOSHIDA, 1992) around in summer and autumn. However, we will not focus on these seasonal variations in this study.

2. The method of data processing

2.1 Interpolation of data and elimination of seasonal variation

The period of analyzed data is about 22 years – from February 1972 to June 1994. Figure 1 shows the location of originally aimed observation points by the Hakodate Marine Observatory. The six points are named Station (Stn.) 1–6 as shown in the figure. The depth of Stn. 1–3 are about 1100–1500m, and Stn. 4–6 over 5000m. Until the summer in 1988, observations had been done by using the Nansen water sampling bottles to obtain the data of temperature, salinity and other chemical properties at the discrete standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 1000 and 1200m). In the Nansen casts,

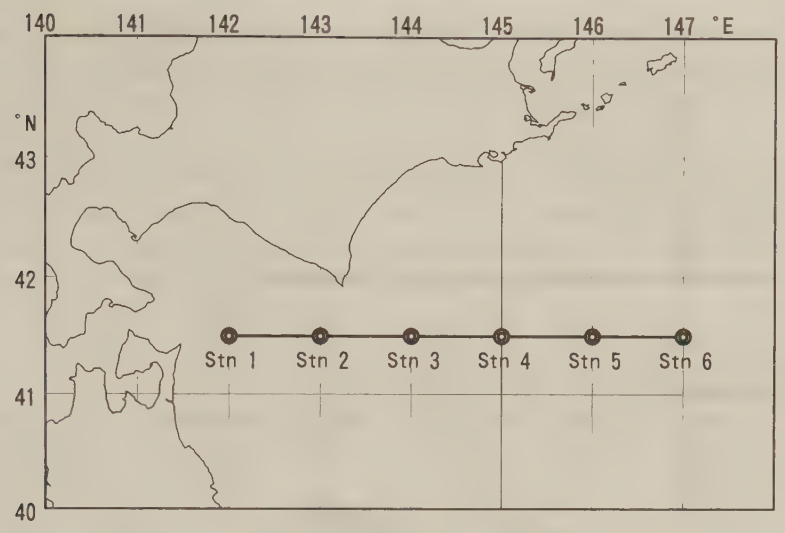

Fig. 1 Station locations.

it is not always possible to obtain the data at desired depths, then the data were linear-interpolated at the standard depths. Since 1988, the CTD system has enabled us to get the data of temperature and salinity continuously from the sea surface to nearly the bottom or a depth of 4000m.

In this study, four elements were chosen to analyze among observed oceanic data – temperature, salinity, dissolved oxygen and Sigma-t (δt) which is calculated from temperature and salinity. Observations have been carried out at least 4 times a year, that is, in every season. Figure

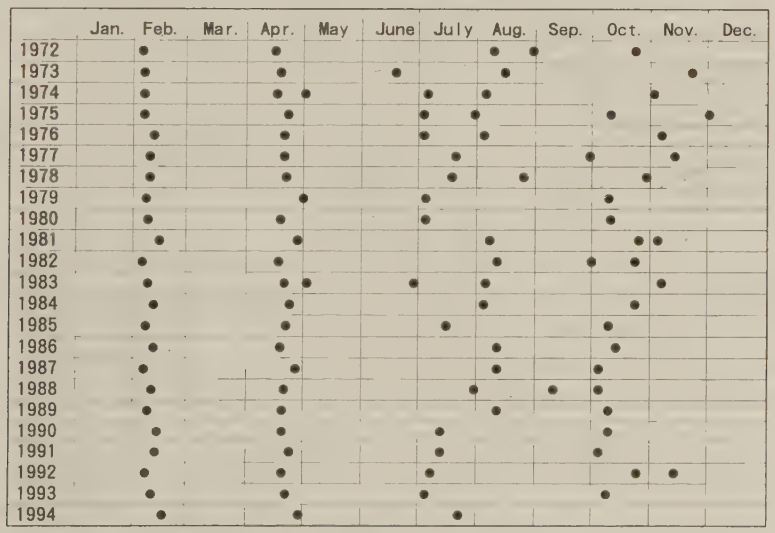

Fig. 2 Observation time over 22 years at Station 3 (41°30'N · 144°E).

2 shows an example of the times of observations at Stn. 3. In winter and spring, the times of observations in a year are relatively fixed – the former half of February and the latter half of April respectively, on the other hand in summer and autumn, they spread over a 2 months period.

Thus, the data were linear-interpolated to a fixed date in each season – February 5 in winter, April 25 in spring, July 25 in summer and October 25 in autumn. Then using the above processed data, seasonal mean values were calculated, and we calculated deviations from the seasonal mean values in order to eliminate the seasonal variations.

3. Results

3.1 Classification of observation Stations

Figure 3 shows the frequency distribution of 100m-depth temperature at the six stations. The

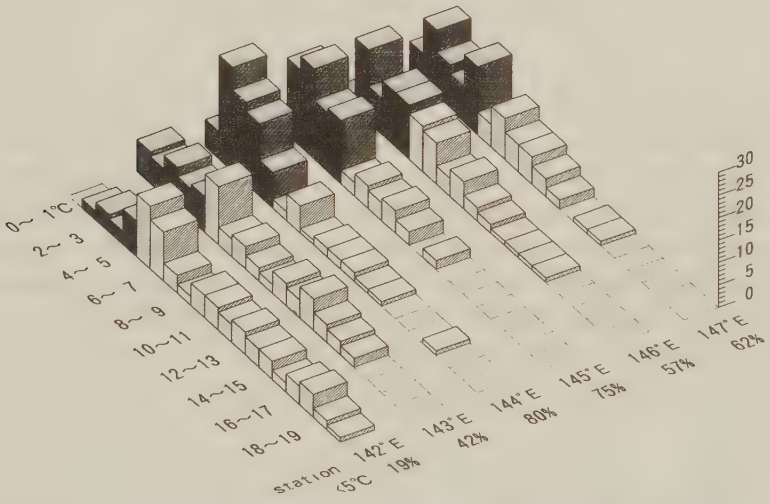

Fig. 3 Frequency distribution of 100m-depth temperature and appearance rate of water below 5°C.

numerals with % in the figure show percentage of the temperature below 5°C which is generally considered as the Oyashio Cold Water. At the central two stations (Stn. 3–4), it appears nearly by 80%, while in the west side (Stn. 1–2) less than 40% and in the east side (Stn. 5–6) about 60%. Mean values were calculated for seven layers (0–50, 50–100, 100–150, 150–250, 250–400, 400–600, 600–800m) to apply the factor analysis (TANAKA *et al.*, 1984) for each element at the six stations. It gave the following result that their variations could be explained by more than 50% in terms of three factors. Figure 4 shows the distribution of the factor loadings as to above three factors. It suggests that the regions with large absolute values generally extend over two stations in most of elements. The large absolute values are found at two east (off

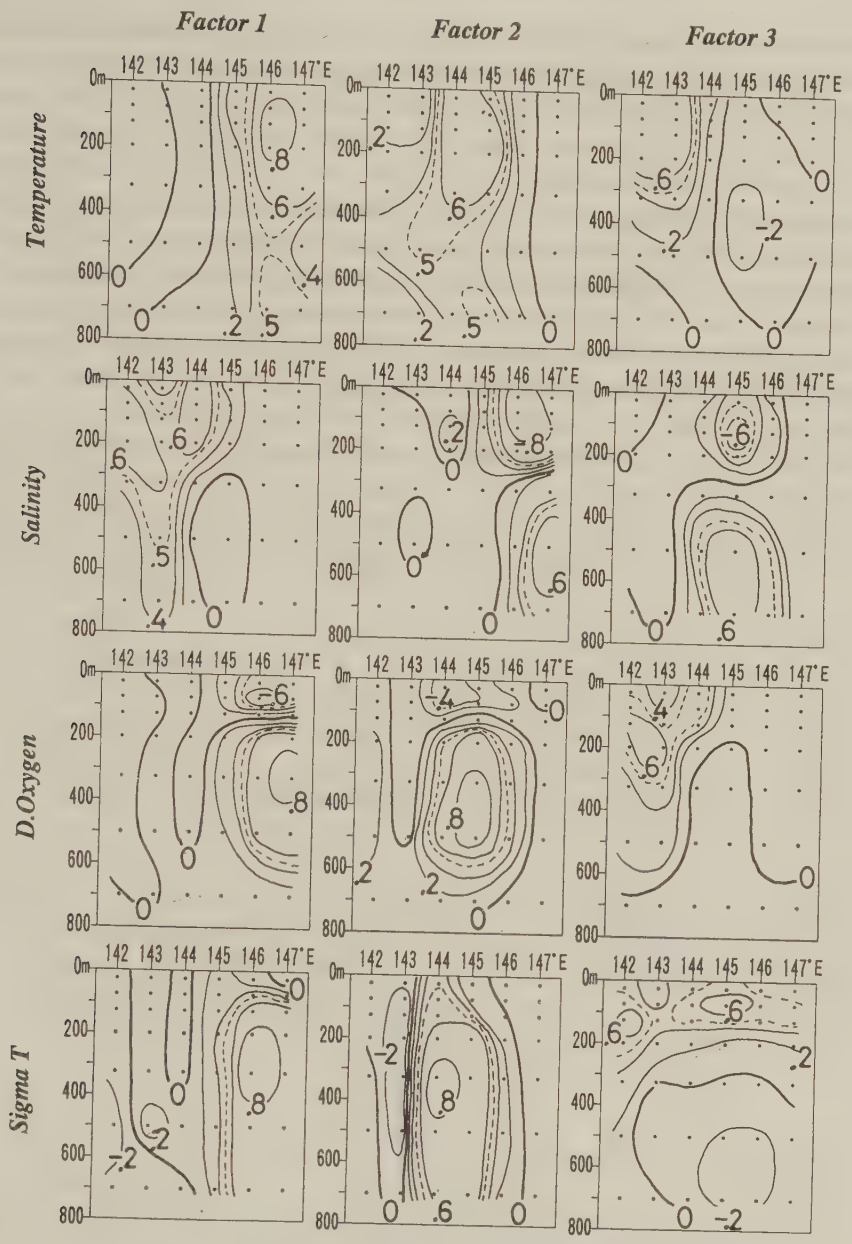

Fig. 4 Distribution of the three factor loadings on the factor analysis applied to four elements.

coast) stations (A) in the first factor of temperature, dissolved oxygen and δt and the second factor of salinity. They are also found at central two stations (B) in the second factor of temperature, dissolved oxygen and δt and the third factor of salinity. Referring to the third factor of temperature and dissolved oxygen and the first factor of salinity, they are found at two or three west side stations (C) above 300m.

Closely examining the figure 4, the followings are found. In the case of (A) and (B), temperature has local minima at a depth around 500m, while salinity and dissolved oxygen inverse their signs at about 300m and 150m respectively. It suggests that their upper and lower layers varies like a seesaw. In the case of (C), all elements have large values at 0–300m as described above.

Contrary to another factors described above, only the third factor of δt has a different characteristic that its large value extends over all stations at layers above 150–200m. We may not reject the possibility of insolation effect on the surface layer in summer.

Figure 5 shows the temperature distribution at 100m-depth in June 21–30, 1994, that is a

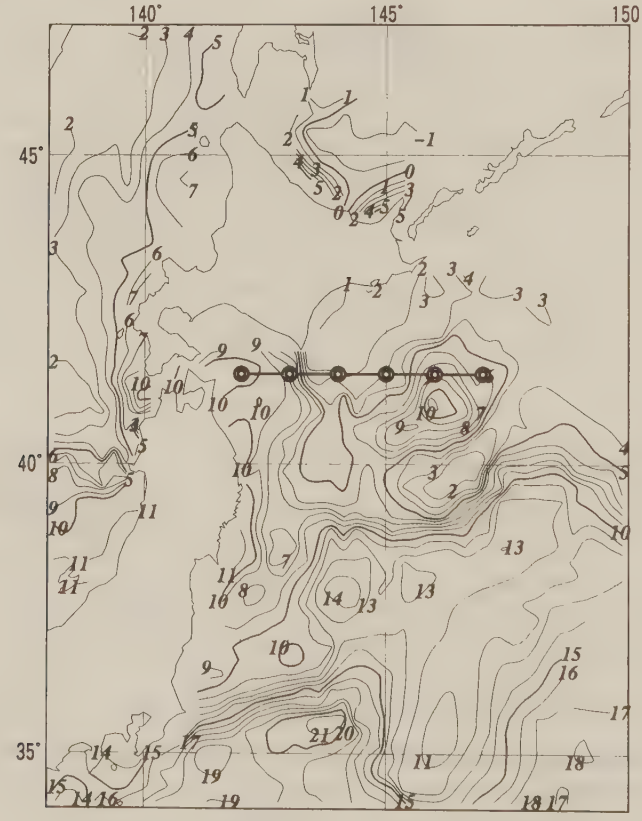

Fig. 5 Temperature distribution at the depth of 100m in June 21–30, 1994.

typical pattern in these sea areas. The west side stations (Stn. 1–2) are covered with the Tsugaru Warm Current which flows into the Pacific through the Tsugaru Strait. The central stations (Stn. 3–4) are covered with the Oyashio Cold Water. The east side stations (Stn. 5–6) are in a warm eddy temporally moving northward.

Considering the results of (A) – (C) with the thermal structure indicated in Figures 3 and 5, we can give a following picture of classification. The two west side stations are strongly under the influence of the Tsugaru Warm Current. The two central stations are covered with the Oyashio Cold Water almost all the time. The two east side stations are often on the trace of warm eddy although they are covered with the Oyashio occasionally.

Then, the six stations are classified into three groups (Stn. 1–2, Stn. 3–4, Stn. 5–6) and named as "the Tsugaru Warm Current Region", "the Oyashio Region" and "the Off Coast Region", respectively, for further analyses.

Referring to the vertical changes shown in Figure 4, the sea water column along the section were redivided into four layers and a representative value of each element in each layer was calculated by integral averaging of the contained levels. — 0–100m depth (0, 10, 20, 30, 50, 75, 100m), 100–200m (100, 125, 150, 200m), 200–400m (200, 250, 300, 400m) and 500–800m (500, 600, 700, 800m) —.

3.2 Long term trends

Figure 6 shows the time series of four elements at 500–800m in "the Oyashio Region" and their regression function lines. The variability in 1976, '81, '85 and '88 include the large negative deviations in salinity and δt, and the large positive ones in dissolved oxygen, although as to temperature, no remarkable deviation is found except the large positive deviation in 1976. This suggests that in the intermediate layer in "the Oyashio Region", variations of temperature are different from those of other elements.

Table 1 notes the linear trends of deviations in four elements calculated by the least square method. The numerals in parentheses indicate t in t-distribution. The larger t means that the trend is statistically more significant. As the number of time series data is 91, it corresponds that they are significant at the level of significance P when

$$tc(\nu \fallingdotseq 90,\ P) < t$$

where ν is a degree of freedom and tc is a critical value of t-distribution described at the lowest part of Table 1.

Periodic analyses on four elements by FFT showed the existence of the dominant variations with a period of 2 – 3 years especially below 200m (Details are not shown here). These variations may disturb the analyses for variability longer than 3 years. In order to remove the effects of variations shorter than 3 years in periods, the data in Table 2 were provided through running-mean for 37 months.

Table 1, without running-mean processing, indicates that there are not any variations with a level of significance below 5% except in "the Oyashio Region" and "the Tsugaru Warm

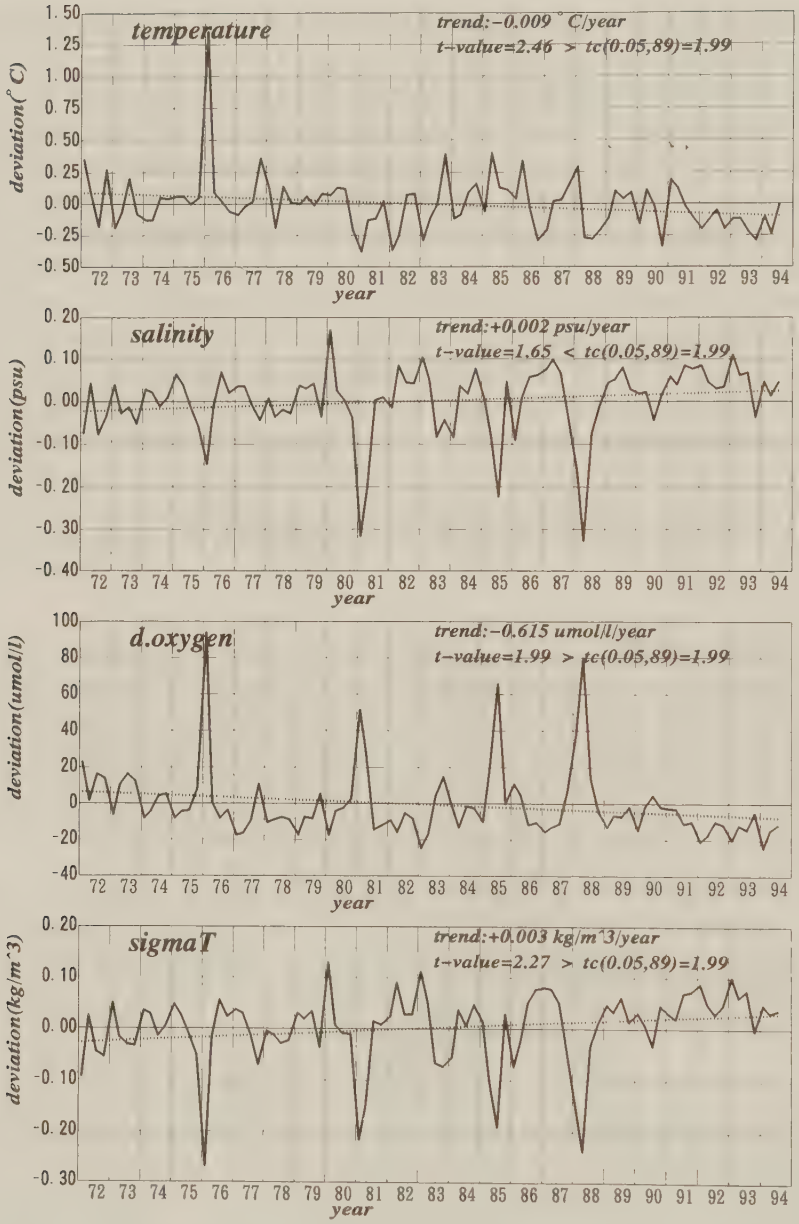

Fig. 6 Deviations (solid line) on the four elements (means for the deviations at Stations 3 and 4) and long-term trends (dotted line).
level: 500–800m, normal: average of 1972–1993.

Table 1 Long-term trends of four elements by least square method.
The numeral in parentheses is statistic value *t*.
⬚ : $t > 1.99$ ▭ : $t > 2.63$ ▭ : $t > 2.88$

Station–1,2

Depth m	Temperature °C/year	Salinity psu/year	D. Oxygen umol/l/year	Sigma T kg/m^3/year
0-100	-0.023 (0.80)	-0.000 (0.01)	+0.07 (0.35)	+0.005 (1.51)
100-200	-0.055 (2.19)	-0.006 (2.10)	+0.39 (1.93)	+0.004 (1.64)
200-400	-0.037 (2.89)	-0.004 (2.55)	+0.05 (0.17)	+0.001 (1.34)
500-800	-0.004 (1.46)	+0.001 (1.15)	-0.28 (1.65)	+0.001 (2.10)

Station–3,4

Depth m	Temperature °C/year	Salinity psu/year	D. Oxygen umol/l/year	Sigma T kg/m^3/year
0-100	-0.069 (2.34)	-0.008 (2.05)	+0.65 (2.59)	+0.004 (2.05)
100-200	-0.066 (2.87)	-0.005 (2.12)	-0.05 (0.20)	+0.004 (3.43)
200-400	-0.018 (1.53)	+0.002 (1.57)	-1.38 (2.66)	+0.003 (3.23)
500-800	-0.009 (2.46)	+0.002 (1.65)	-0.62 (1.99)	+0.003 (2.27)

Station–5,6

Depth m	Temperature °C/year	Salinity psu/year	D. Oxygen umol/l/year	Sigma T kg/m^3/year
0-100	-0.003 (0.09)	-0.002 (0.45)	-0.03 (0.11)	-0.001 (0.65)
100-200	-0.038 (1.23)	-0.003 (0.87)	-0.07 (0.21)	+0.002 (1.62)
200-400	-0.011 (0.74)	+0.002 (1.24)	-0.86 (1.23)	+0.003 (2.00)
500-800	-0.005 (1.25)	+0.002 (1.19)	-0.27 (0.76)	+0.002 (1.51)

t–distribution critical value (tc)

P / ν	0.05	0.01	0.005
80	1.990	2.639	2.887
90	1.987	2.632	2.878
100	1.984	2.626	2.871

Table 2 Same as Table 1 but the data were running-averaged for 37 months.
[ ] : $t > 1.99$ [ ] : $t > 2.63$ [ ] : $t > 2.88$

Station-1,2

Depth m	Temperature °C/year	Salinity psu/year	D. Oxygen umol/l/year	Sigma T kg/m^3/year
0-100	-0.021 (2.54)	+0.000 (0.44)	+0.04 (0.89)	+0.005 (6.13)
100-200	-0.056 (9.42)	-0.005 (9.08)	+0.34 (8.22)	+0.004 (6.88)
200 400	-0.037 (12.44)	-0.004 (11.41)	-0.03 (0.33)	+0.001 (7.17)
500-800	-0.003 (3.99)	+0.001 (5.73)	-0.36 (7.45)	+0.001 (10.67)

Station-3,4

Depth m	Temperature °C/year	Salinity psu/year	D. Oxygen umol/l/year	Sigma T kg/m^3/year
0-100	-0.062 (10.05)	-0.007 (7.38)	+0.56 (11.15)	+0.004 (9.56)
100 200	-0.060 (14.06)	-0.004 (8.43)	-0.10 (1.60)	+0.004 (16.68)
200 400	-0.014 (7.10)	+0.002 (9.08)	1.36 (10.57)	+0.003 (15.08)
500-800	-0.008 (12.34)	+0.002 (8.67)	-0.60 (9.14)	+0.002 (12.28)

Station-5,6

Depth m	Temperature °C/year	Salinity psu/year	D. Oxygen umol/l/year	Sigma T kg/m^3/year
0 100	-0.010 (1.34)	-0.003 (3.58)	+0.03 (0.53)	-0.001 (2.87)
100 200	-0.045 (7.35)	-0.003 (5.38)	0.12 (2.06)	+0.003 (10.59)
200-400	0.013 (6.44)	+0.002 (9.29)	-1.12 (7.37)	+0.003 (11.77)
500 800	-0.005 (7.70)	+0.002 (6.37)	-0.41 (5.49)	+0.002 (8.04)

Current Region" below 200m. But Table 2, with running-mean processing, indicates that statistic values t are much larger than those of Table 1 because variations with short periods were removed. While long term trends don't have any remarkable differences between Table 1 and 2.

Long term trends found in the variability of individual elements in Table 2 were as follows.

Temperature Temperatures in all the vertical layers and areas have the decreasing trends. Especially, above 200m in "the Oyashio Region", it shows a remarkable decrease of about 0.06°C par year. Descents of 0.008 – 0.014°C/year are also recognized below 200m.

Salinity Long term trends have different tendencies between upper and lower layer except

in the layer of 0–100m depth in "the Tsugaru Warm Current Region" whose trend is not significant statistically. In "the Tsugaru Warm Current Region", it decreases by about 0.004 — 0.005psu/year in the layer of 100–400m depth, whereas it increases by about 0.001psu/year in the layer of 500–800m depth. In "the Oyashio Region" and "the Off Coast Region", it decreases by 0.003 – 0.007psu/year in the layer of 0–200m depth, while it increases by 0.002psu/year below 200m.

Dissolved oxygen The observed data just below the sea surface sometimes include so much noises that it is difficult to determine whether they are statistically significant or not. Below such uppermost layers, increase in the upper layers and decease in the lower layers are confirmed as opposed to the trends of salinity. In "the Oyashio Region", it increases by 0.56 μmol/l/year in the layer of 0–100m depth, while it decreases by 0.60 – 1.36 μmol/l/year in the layer of 200–800m depth.

Sigma-t Although it decreases in the layer of 0–100m depth in "the Off Coast Region", it increases by 0.001 – 0.005kg/m^3/year in all other areas.

3.3 Relationship with other meteorological and oceanic elements

The observed area is located in the western boundary of the Subarctic Gyre of the north Pacific Ocean, that means the obtained data could have close relationships with other meteorological and oceanic elements through the oceanic and atmospheric circulations of a ocean basin scale of Pacific. Periodic analyses showed dominant periodicities of 2 – 3 years mainly below 200m as mentioned above. In this section, elements selected from "the Oyashio Region" were compared with a variety of meteorological and oceanic elements, which may influence the strength of the Oyashio.

Figure 7 shows time series of δt in the layer of 500–800m depth in "the Oyashio Region" and SST in the region of 4°N – 4°S·150°W – 90°W, which is one of monitorring areas of SST to detect the occurrence of El Niño events by the JMA. Their cross-correlation is also shown in the figure. These figures indicate the existence of a close relationship and the phase of variation of δt is 4 months earlier than that of SST.

Other elements relating with ENSO events (Southern Oscillation Index, deviation of zonal wind at 850hPa in Equatorial Pacific, oceanic observation data along 137°E by "Ryofu-maru" of the JMA, etc.) were also investigated to show that they have close relations with δt and their phases are several months later than that of δt.

Figure 8 is the same as Figure 7 except a layer of δt is 0–100m, but no noticeable relationship is existed between the two.

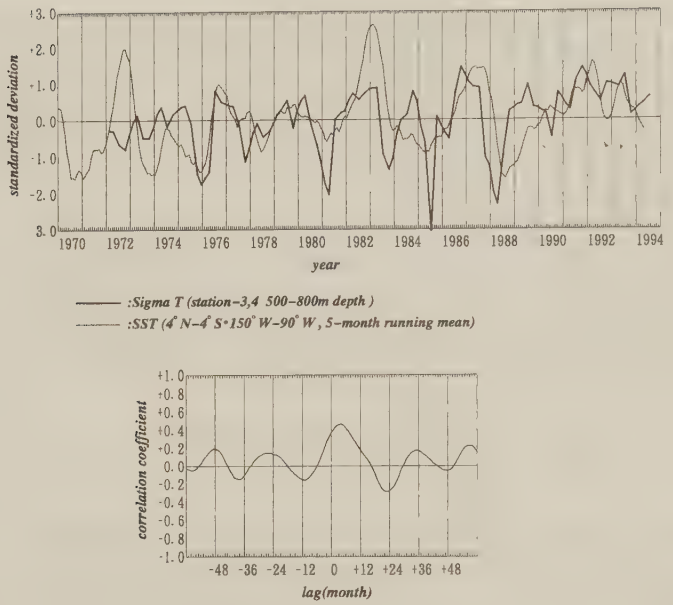

Fig. 7 Time series of standardized deviation of Sigma-t and SST at Equatorial Pacific (upper) and their cross-correlation (lower). Negative lag means a phase of Sigma-t variation is behind with that of SST.

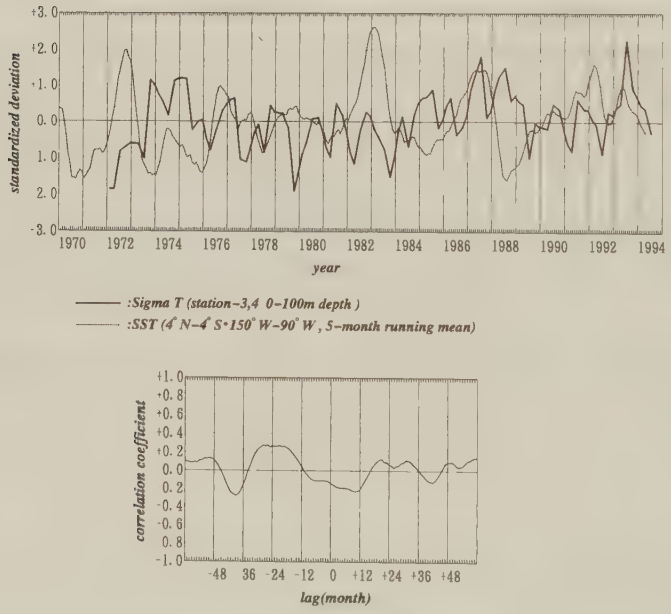

Fig. 8 Same as Fig. 7 but the layer of Sigma-t is 0–100m.

4. Discussion

In "the Oyashio Region" in the layer of 500–800m depth, temperature has a different variability compared with other elements (Fig. 6). This is clearly seen by the results that correlation coefficients with δt are 0.40 in temperature, 0.96 in salinity and –0.90 in dissolved oxygen.

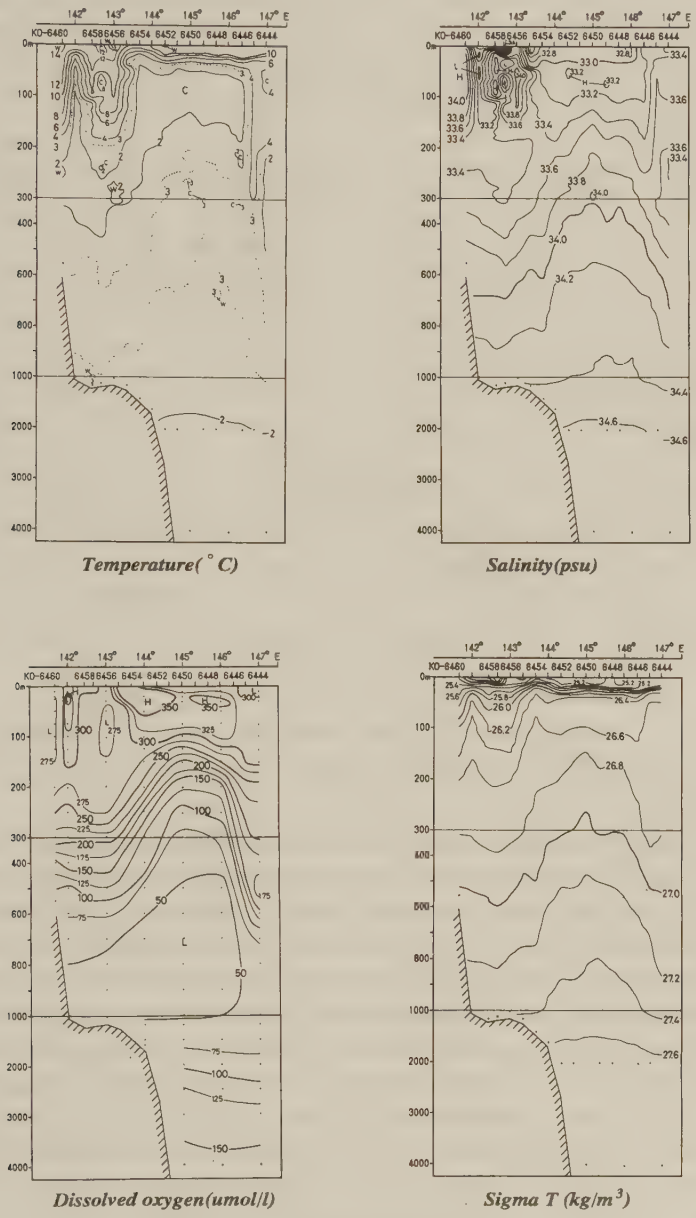

Fig. 9 Vertical profiles of elements along 41°30'N in July 1993.

Figure 9 shows the vertical profiles of elements along 41°30'N in July, 1993. Below 300m in "the Oyashio Region", seasonal variations are so slight that nearly the same profiles appear all through the year. Temperature has a gentle maximum in the layer of 300–800m depth. The layer at 500–800m depth whose data were analyzed in the previous section is located in the lower part of the maximum, and doesn't have a noticeable vertical gradient. On the other hand, both of salinity and δt increase with depth. Dissolved oxygen decreases with depth at 500–800m although it has a minimum at 800–1000m. Thus, the elements other than temperature have clear vertical gradients and such a difference of vertical profiles may result in the different variability in Figure 6.

Figure 10 shows a relation between mean temperature/(salinity) in the layer of 50–100m depth

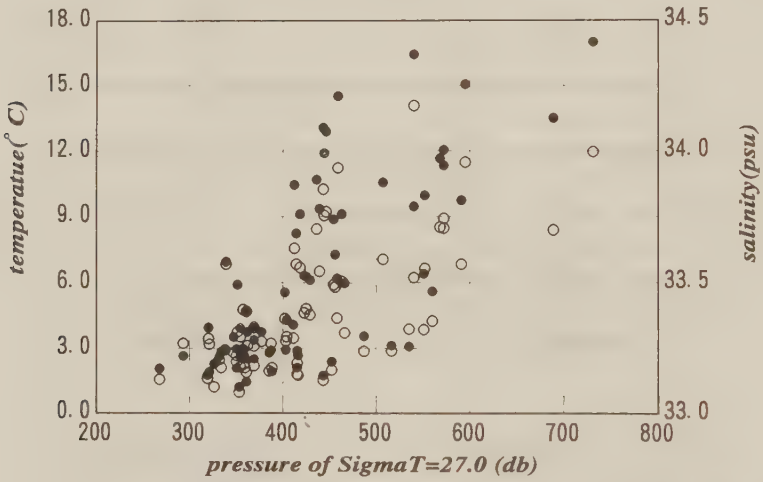

Fig. 10 Mean temperature (○) and salinity (●) at the layer of 50-100db compared with pressure of Sigma-t=27.0.

of Stn. 4, 5, 6 observed by the CTD system from 1988 onward and depth/(pressure) of isopycnic where δt = 27.0. Temperature/(salinity) increases with depth/(pressure), which suggests that water mass with high temperature and salinity derived from Kuroshio flows into subsurface, and it makes the layer of the subsurface thick. Since "the Oyashio Region" is covered with the Oyashio water almost all the time as described in 3.1 and a different kind of water mass seldom flows into there through horizontal advection, the flow of warm water gives a remarkable effect on the time series of deviation. The primary cause of the variation at the intermediate layer in "the Oyashio Region" is considered to be the variation of thickness of subsurface water resulted from the inflow of warm water or the coverage of the Oyashio.

On referring to δt and salinity/(dissolved oxygen) in Figure 6, negative/(positive) spikes are found. This suggests that we observed relatively shallower water pushed down by upper warm water, as viewed from the concurrent horizontal temperature distribution in the sea areas where

warm water mass such as a Warm Eddy always existed at subsurface layer of Stn. 3. or 4.

Intensity of long-term trend in temperature along 41°30'N during 20 years is decreasing from subsurface to intermediate layer. This decreasing trend agrees with another results by Ishida and Ogawa (1989) or Kutsuwada (1990) observed in sea area east of Honshu.

The decreases in temperature and salinity and the increase of dissolved oxygen were found during a period of observation at subsurface in "the Oyashio Region", while the increase in salinity and the decrease in dissolved oxygen were found at intermediate layer. The decreases of temperature and salinity and the increase in dissolved oxygen correspond to the strengthening of the characteristics of the Oyashio Water.

Figure 10 also suggests that the warm water mass which flows into the subsurface layer could make the layer thicker, and push down the boundary of subsurface layer and intermediate layer, and vice varsa. Therefore the increase of salinity and the decrease of dissolved oxygen at intermediate layer result from the thinning of the subsurface layer by the less active inflow of the warm water mass or much intensive inflow of the cold water mass.

Variations related to the ENSO events are found at intermediate layer (500–800m), but not found at subsurface layer. Although this may contradict the suggestion that variations at intermediate layer are dominated by mainly those at subsurface, this can be regarded that signals of ENSO events are masked with another variations.

The trends calculated in this study are valid only within a period of the data (about 20 years), but this is not long enough to extract long-term variations over 10 years. Continued observations for a longer period to the future are necessary to answer the following questions.

— whether these trends are parts of global changes affected by the interaction between atmosphere and ocean such as climatic changes, or they are parts of self-inductive oscillations only of ocean with a period of several decades shown by numerical models.

5. Summary

Using oceanographic observation data in 22 years mainly observed by the Hakodate Marine Observatory, variability of the oceanic conditions from sea surface to intermediate layer in the sea area south of Hokkaido was investigated. The results are summarized as follows.

From the factor analysis, the six stations could be classified into three groups and they were usually covered with the Tsugaru Warm Current, the Oyashio and the warm eddy, respectively.

Long term trends were investigated. Trends in temperature were the decreasing ones at all regions and layers. The decreases of salinity and the increase of dissolved oxygen were found at subsurface, while the increase of salinity and the decrease of dissolved oxygen at intermediate layer. These trends are results of the frequently southward intrusion of the Oyashio cold waters in the 1980's or later.

Furthermore, the variations at intermediate layer (500–800m) in "the Oyashio Region" had close correlations with the ENSO events.

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北海道南方41°30'N線断面における長期変化傾向とENSOと関連した変動

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1972年冬~1994年夏までの北海道南方の41°30'Nに沿った142~147°Eの6個の観測点での海洋観測データを使い、表層から中層までの海況の変動特性を調査した。

各要素の変動状況から6個の観測点は西から2点ずつにグループ分けできて、それぞれ津軽暖流、親潮、親潮と暖水塊の影響を強く受けていることがわかった。長期的な変化傾向は、水温は表層から中層にいたるまで低温化傾向であった。塩分と溶在酸素は表層と中層では変化傾向が異なっており、塩分は表層で低塩分化、中層で高塩分化している。これに対して溶在酸素は塩分とは逆に表層で高濃度化、中層で低濃度化している。これら長期的な変化傾向は、1980年代以降親潮第一分枝の南下が頻繁になっていることによると考えられる。

また親潮域の中層では約2~3年周期の変動がみられ、南方振動指数や赤道域の東西風指数、気象庁凌風丸の137°Eにおける熱帯域の観測資料等のENSOの指標となる要素の変動との関連が示唆された。

本誌に掲載された論文等の著作権は気象庁に帰属する。本誌に掲載された論文等を複製、転載、翻訳、その他に利用する場合は気象庁の承諾を得なければならない。ただし、引用等の利用は出所を明示すれば気象庁の許諾は必要としない。

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